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Environmental Science Institute

Hot Science - Cool Talk # 106

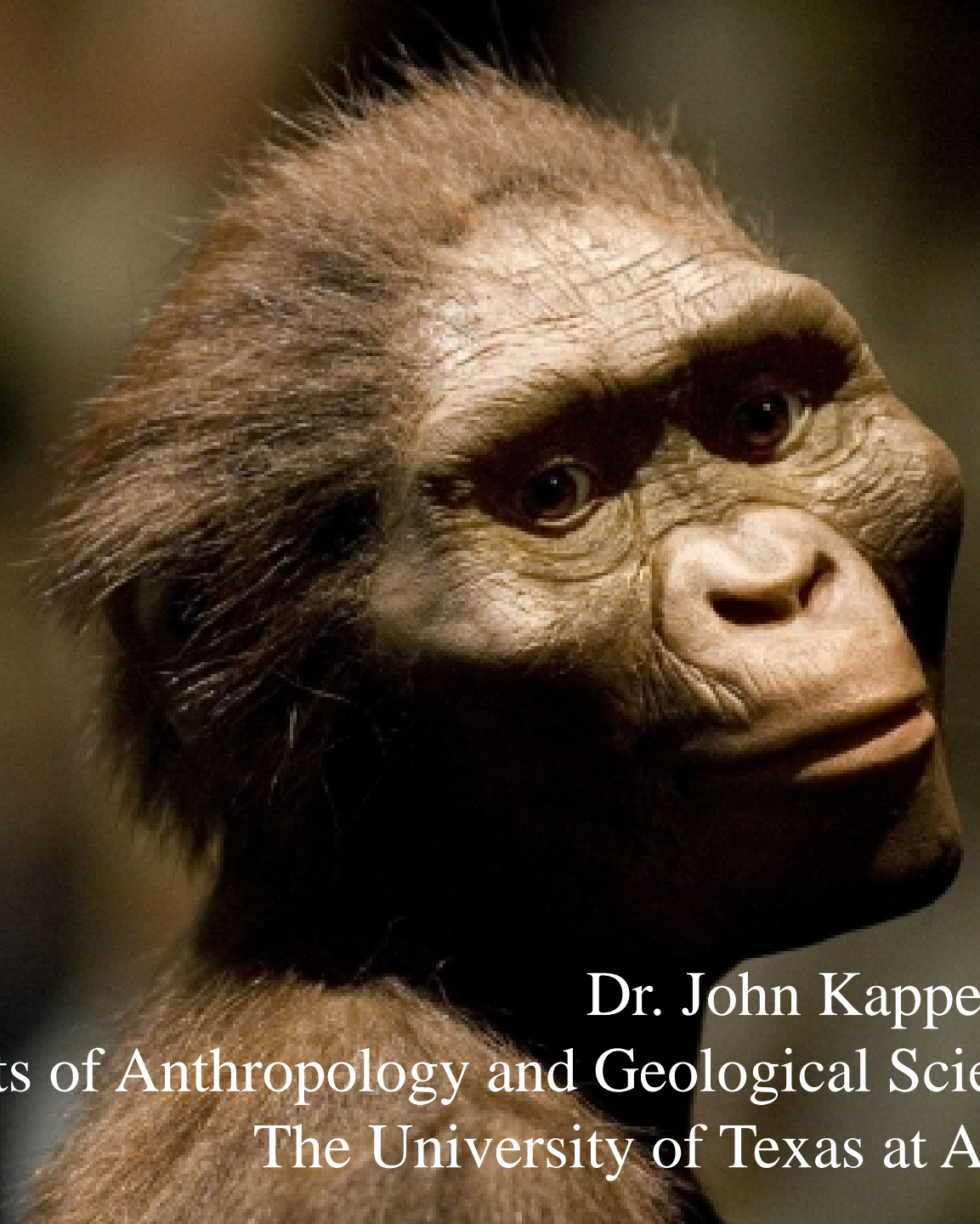
***Solving a 3.2-Million-Year-Old
Mystery: How Lucy Died***

**Dr. John Kappelman
March 24, 2017**

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Solving a
3.2 Million
Year Old
Mystery:

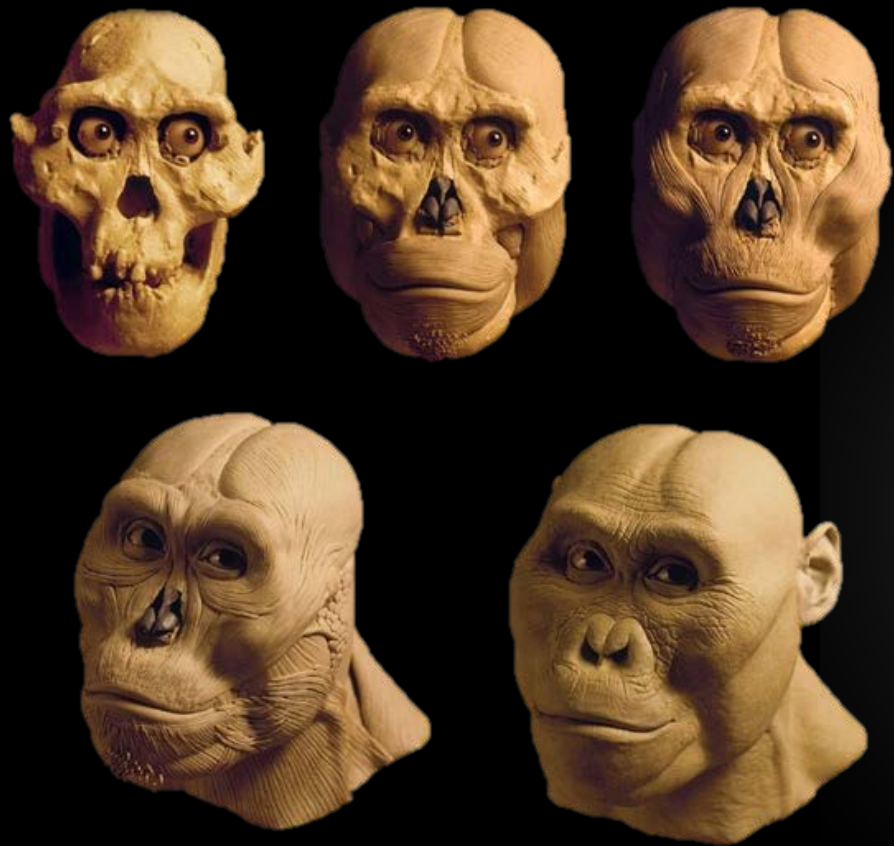
*How Lucy
Died*



Dr. John Kappelman
Departments of Anthropology and Geological Sciences
The University of Texas at Austin

Paleontology: study of ancient life





Copyright John Gurche /
Courtesy Yale University Press

Why study human evolution?

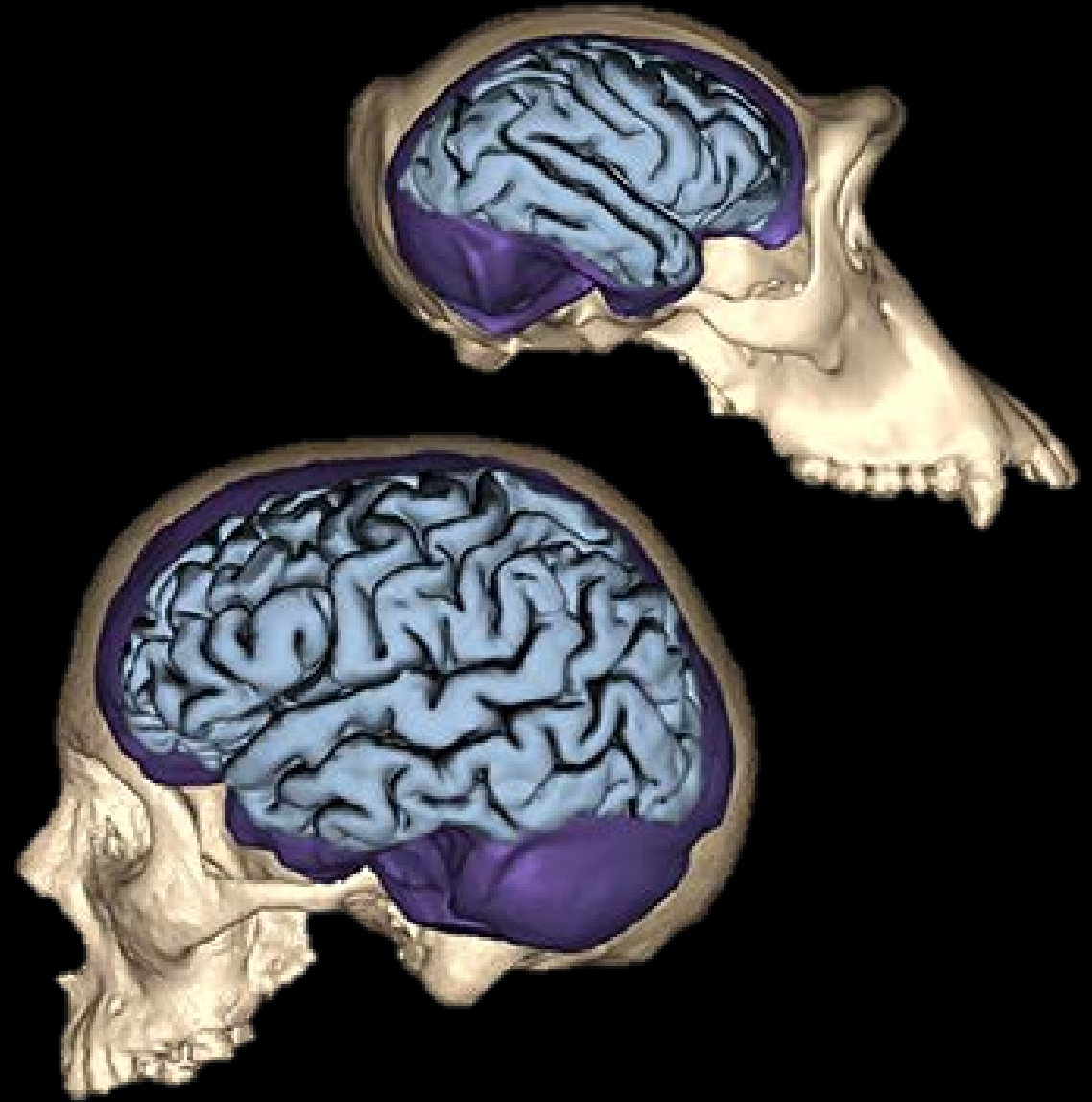
How did natural selection shape our ancestors, and us, across 7 million years (Ma)?

Characteristic features:

Big brains: ~2 Ma

Tool use: ~2.5 Ma, maybe older?

Bipedal: walking on two legs instead of four (quadrupedal): certainly in Lucy at > 3 Ma, and perhaps as old as 7 Ma



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<https://blogs.scientificamerican.com/thoughtful-animal/for-chimps-tool-choice-is-a-weighty-matter/>

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Why study Lucy?

Fossil has been studied for > 40 years

What else is there to discover?

Lesson in how science works

Science builds upon past work,
brings new approaches and
new perspectives to future work

Egalitarian: anyone can do it!

Lucy, the most famous fossil on our planet



President Obama and Lucy
Addis Ababa, Ethiopia, 2015

Lucy: young adult female of *Australopithecus afarensis*

Place: Hadar, Afar Depression,
Ethiopia; also Kenya & Tanzania

Age: 3.18 Ma; range 3.9 – 2.9 Ma

Sample: >400 specimens

Paleobiology: males larger than females
(more like gorillas than humans)

Paleohabitat: wooded savanna mosaic

Locomotion: walked on two legs
(bipedal) when on the ground;
debated whether she climbed trees



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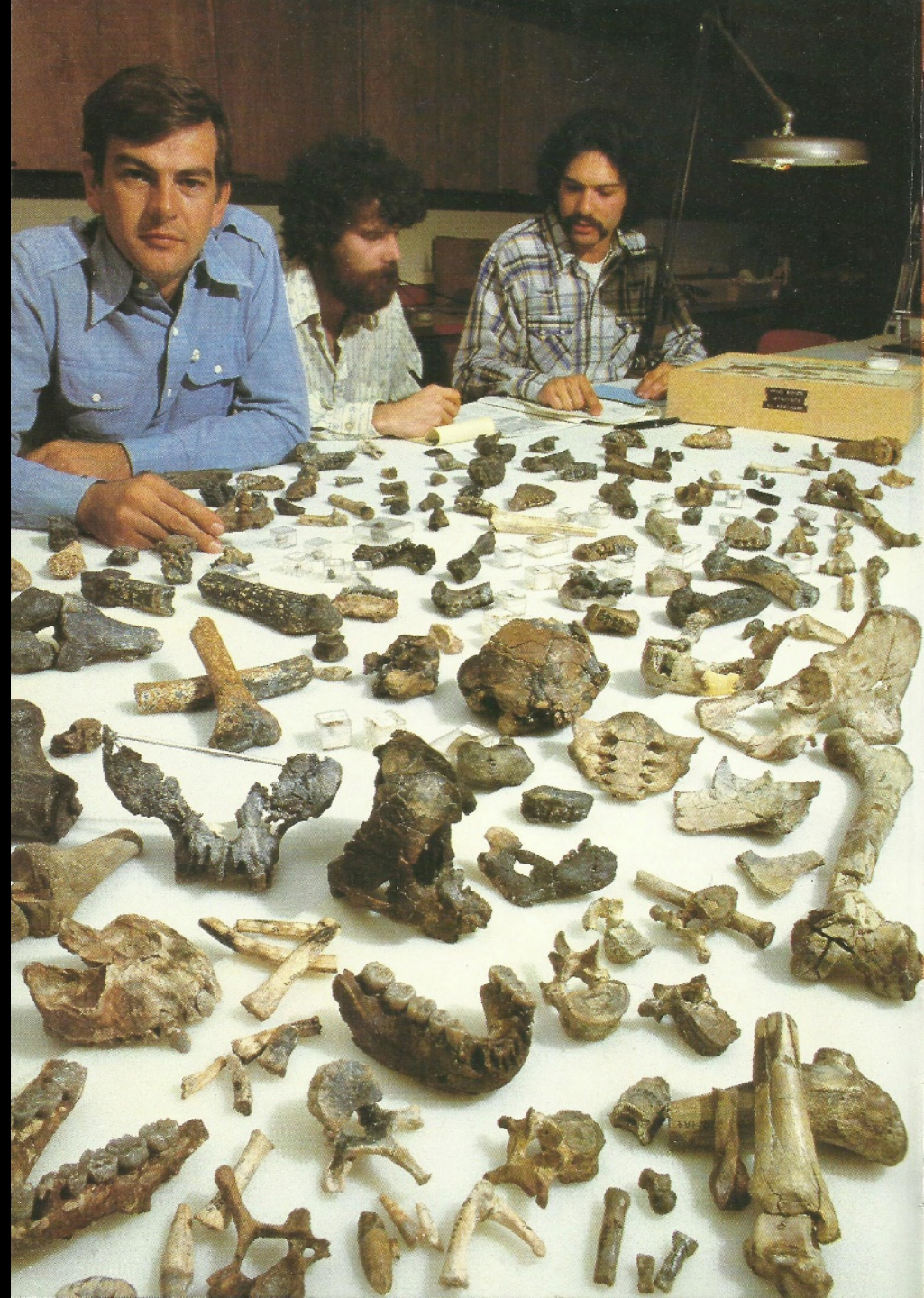
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Female

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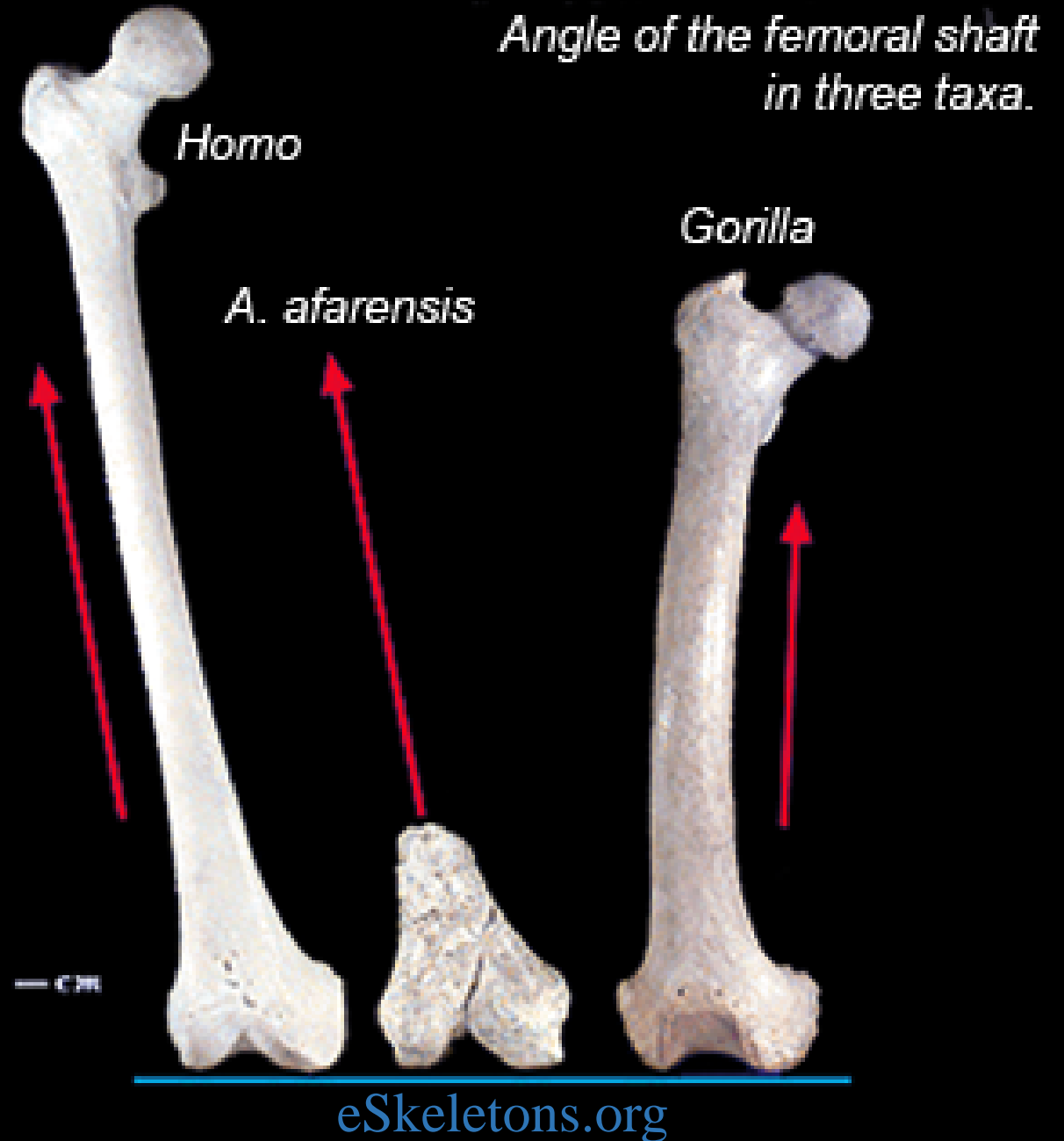


Basis for the debate:
*how to interpret the
anatomy?*

Femur (thighbone)

*Bipeds: hips apart, knees
close together*

Quadrupeds: knees apart

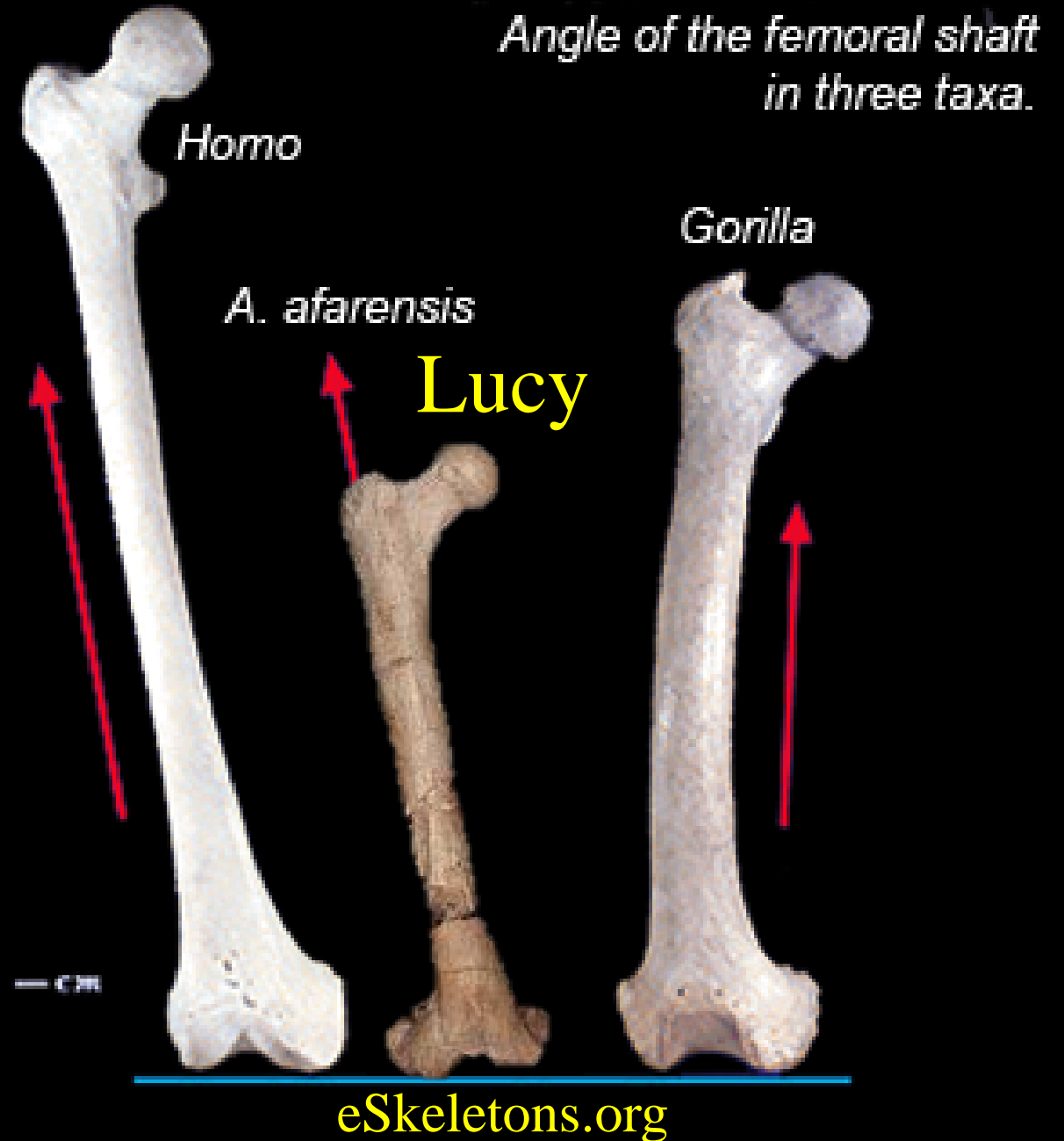


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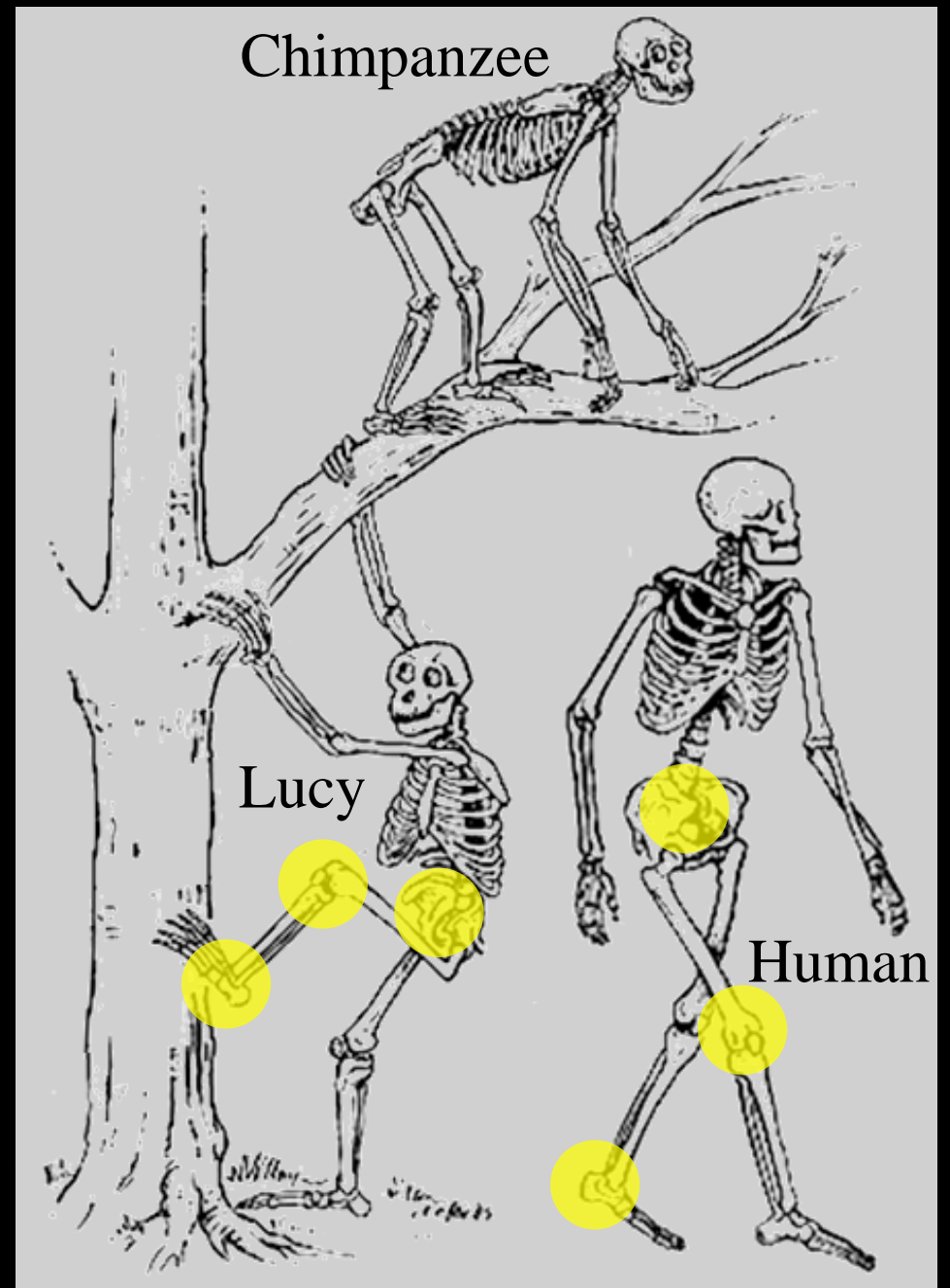
Quadrupeds: knees apart



Basis for the debate:
*how to interpret the
anatomy?*

Comparative anatomy:

*- shared similarities with
bipedal humans*

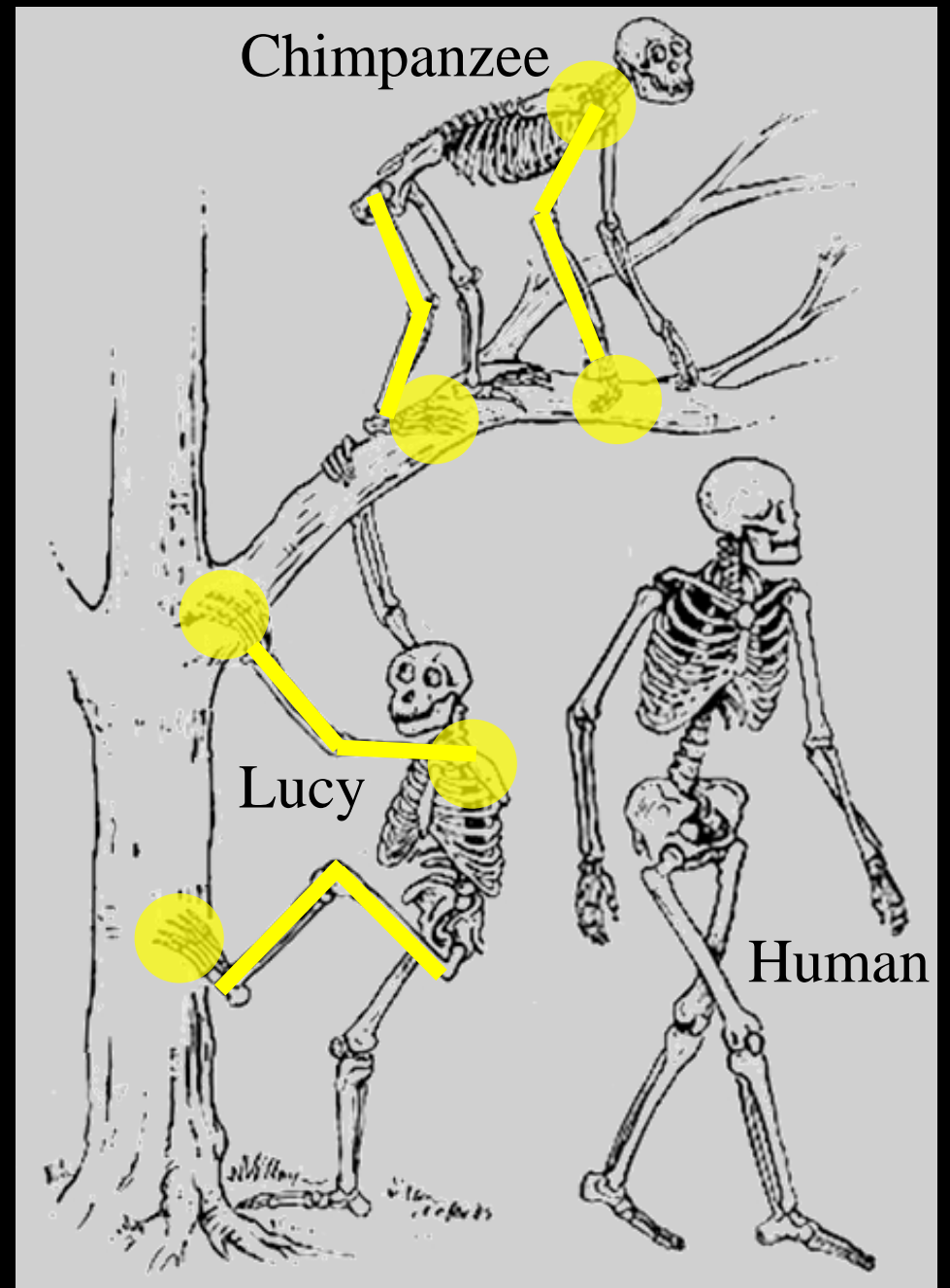


Fleagle. *Primate Evolution and Adaptations.*

Basis for the debate:
*how to interpret the
anatomy?*

Comparative anatomy:

- *shared similarities with
climbing chimpanzees*



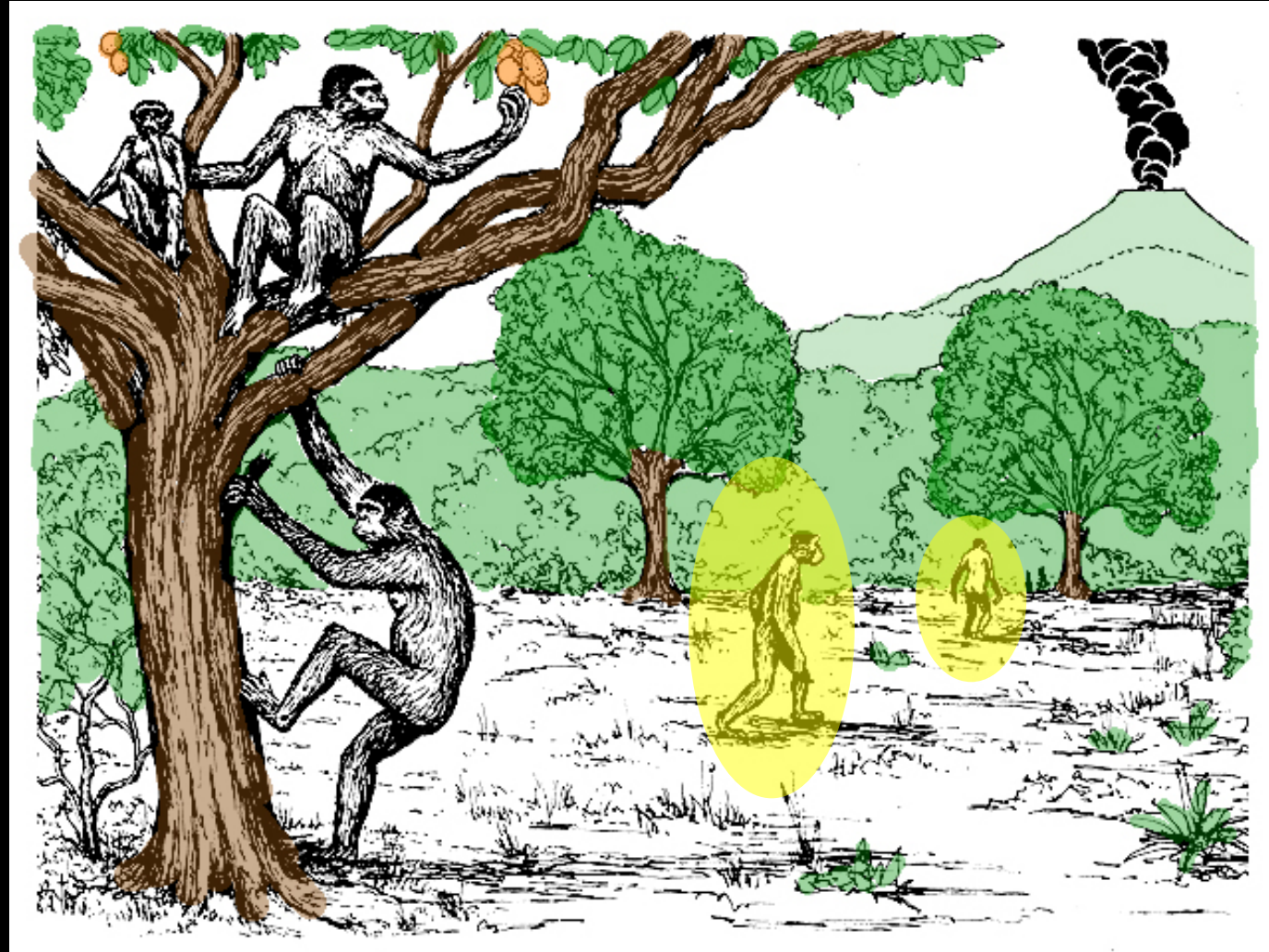
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How did Lucy and other early human ancestors move?

Two sides of a vigorous debate:

1) On two legs (bipedal) only; climbing features no functional significance, only *inherited* from an ancestor who climbed

2) Bipedal, yes, but also climbed trees

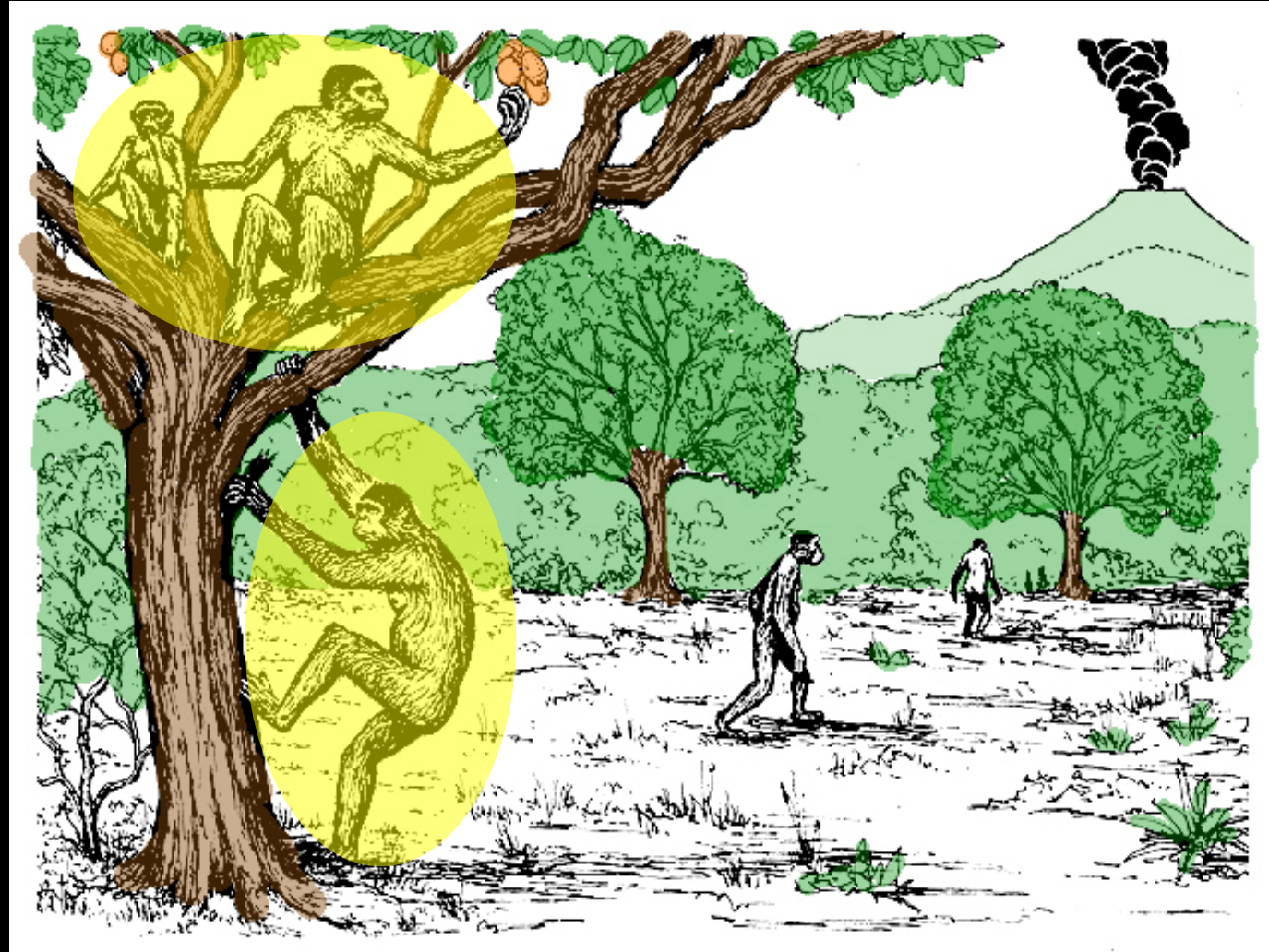


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Debate stalled for 35 years.

Traditional methods for studying the skeleton:

- Calipers (measure size)
- Microscopes (examine fine detail)

Techniques told us about **size** and **shape** but did not answer the question of **function**.



Traditional methods for studying the skeleton:

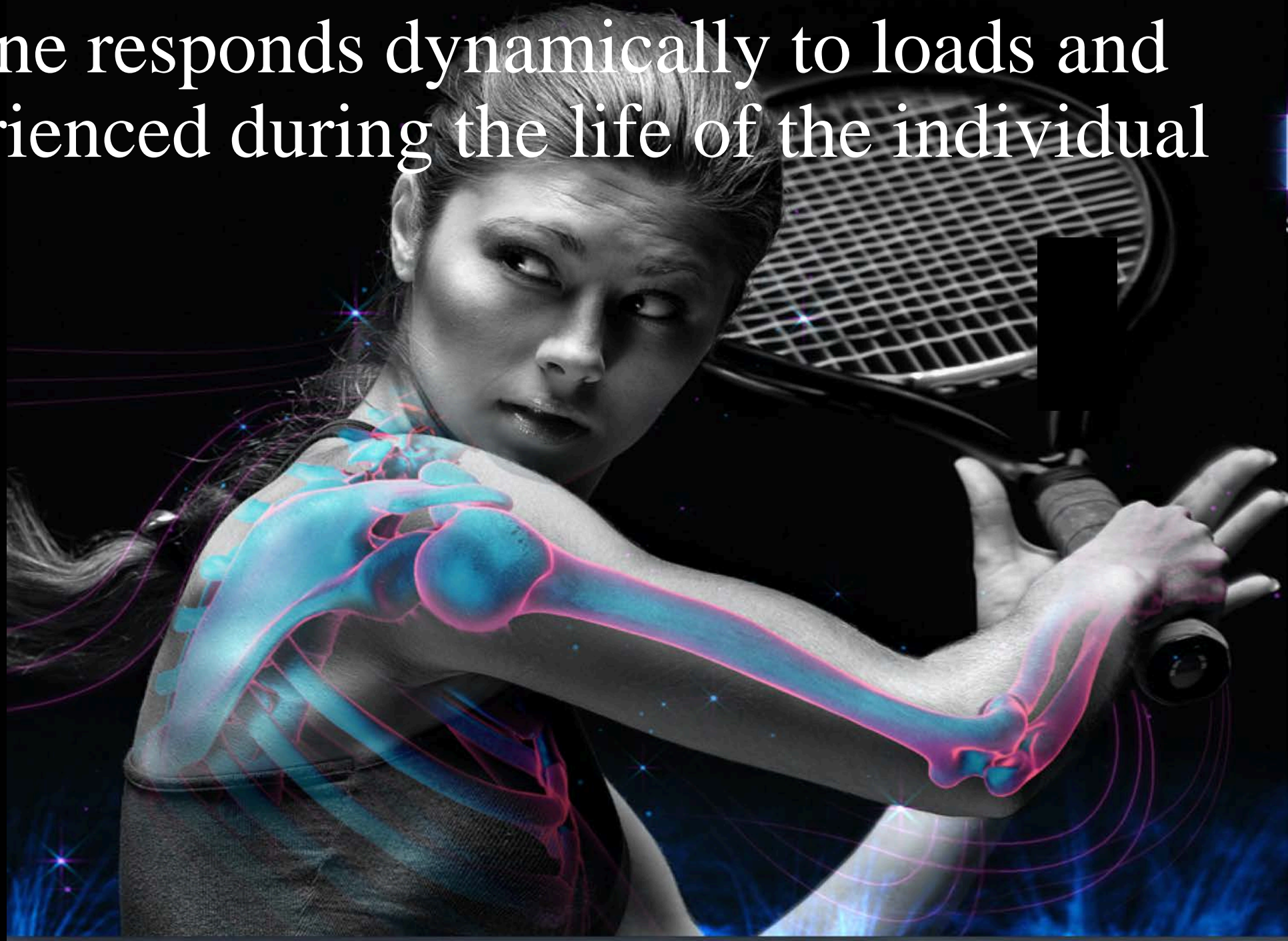
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Techniques told us about **size** and **shape** but did not answer the question of **function**.

*We needed a different approach,
and different techniques,
to test the question.*



Biology: bone responds dynamically to loads and forces experienced during the life of the individual

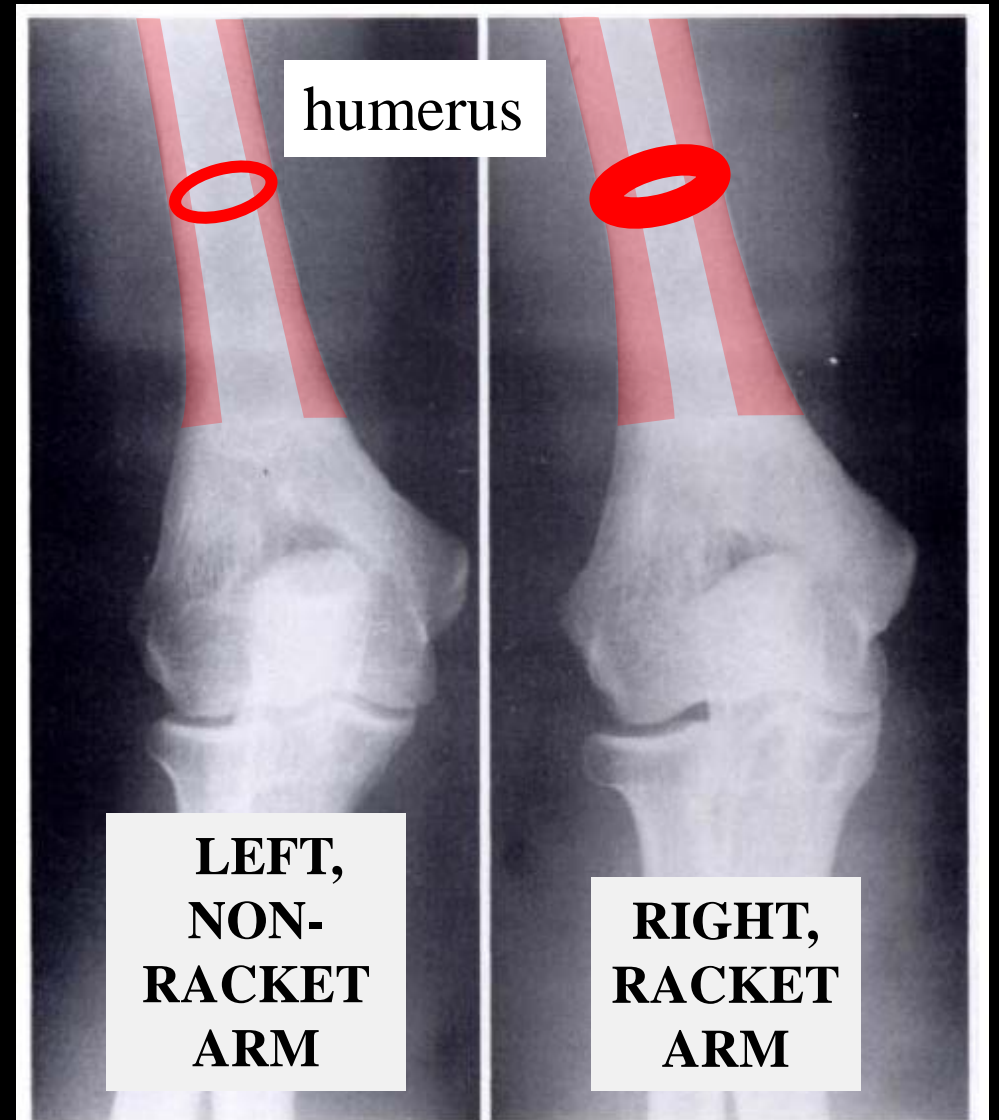


Use X-rays to look inside bones and study the cross-sectional geometries

Bone of the racquet arm (humerus) is thicker than non-racquet arm = greater strength

WHY? Bone responds dynamically to the loads and forces experienced **DURING** the life of the individual

The arm is **STRONG** because it developed through use, NOT because it was inherited from a parent who had one arm that was strong than the other

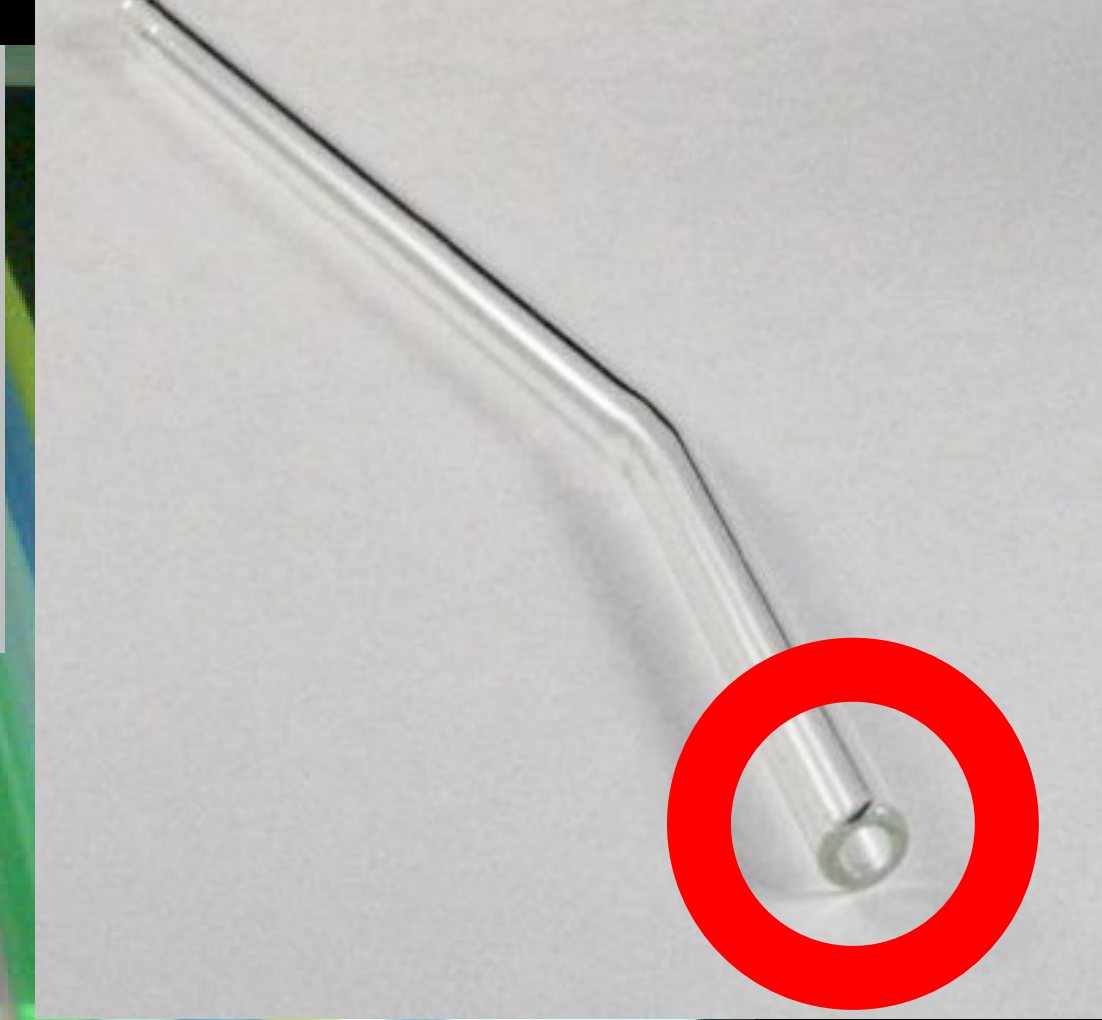


Upper arms of 23 year old right-handed tennis player who started at age 9.

Cross-sectional geometry

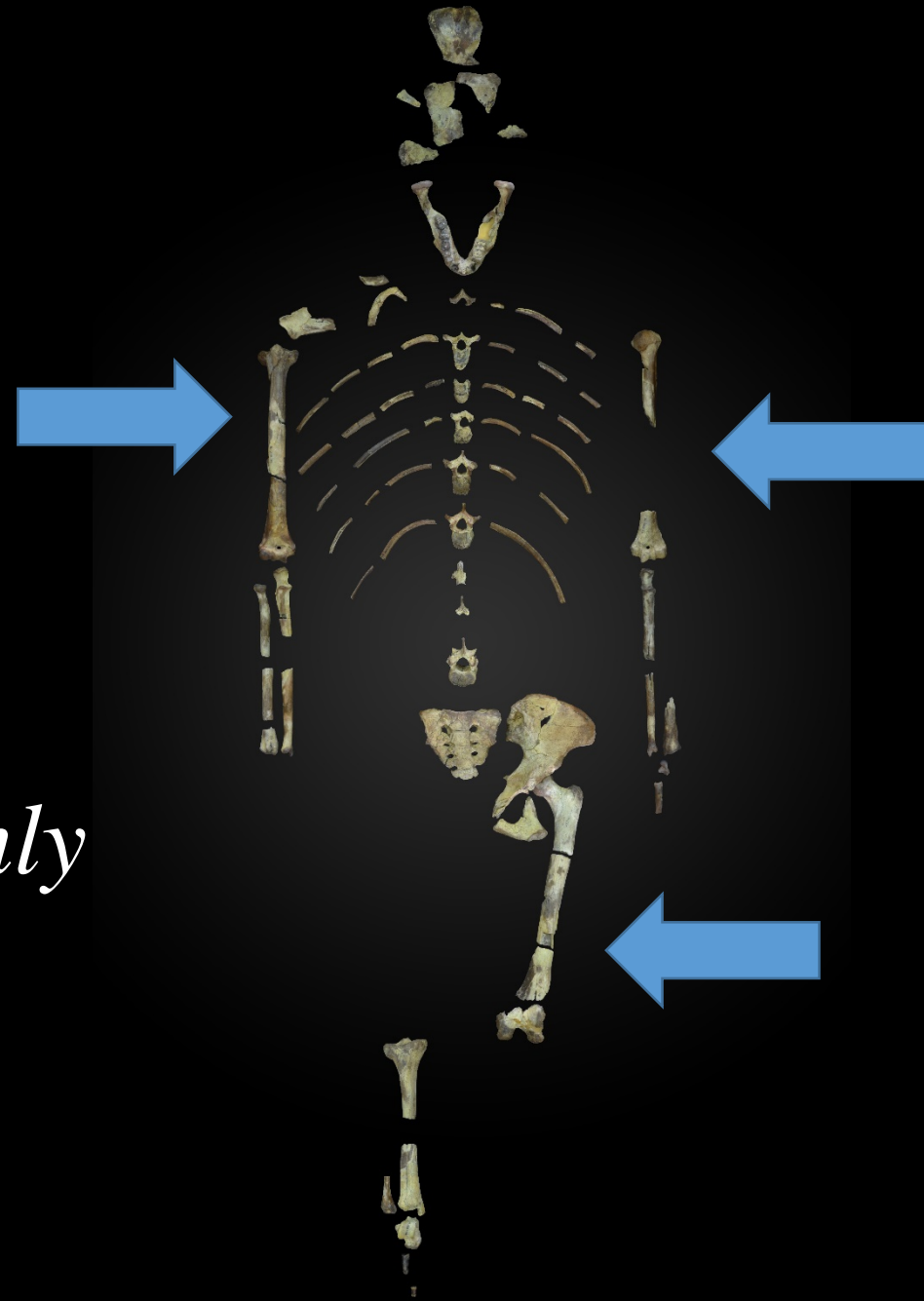
Greater wall thickness

- greater strength
- more resistance to bending



This study of limb bone architecture requires elements from the same individual.

Lucy is one of the only early human fossils complete enough to permit this study.



Need X-rays to see inside the bones, and computed tomography (CT) is best because we can obtain 3D images.



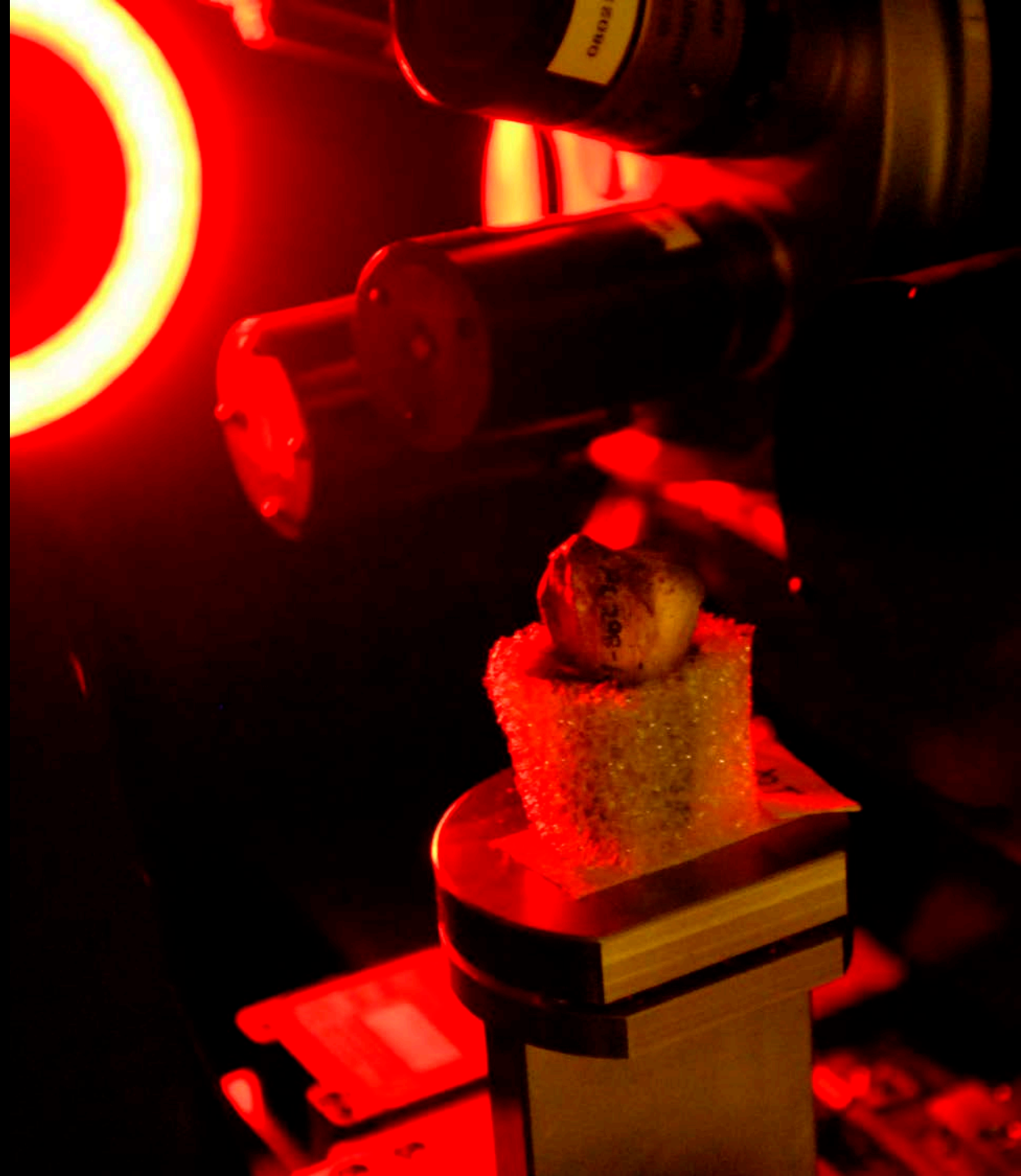
Perhaps your
pet has had a
CT scan?

*(“Rover: sit
and stay!”)*



High-resolution high-energy X-ray CT scanning

- Medical CT good for living people, not good for fossils
- Dream was to scan Lucy but room-sized 20 T lead box does not travel
- Lucy would have to come to UT Austin which was highly unlikely



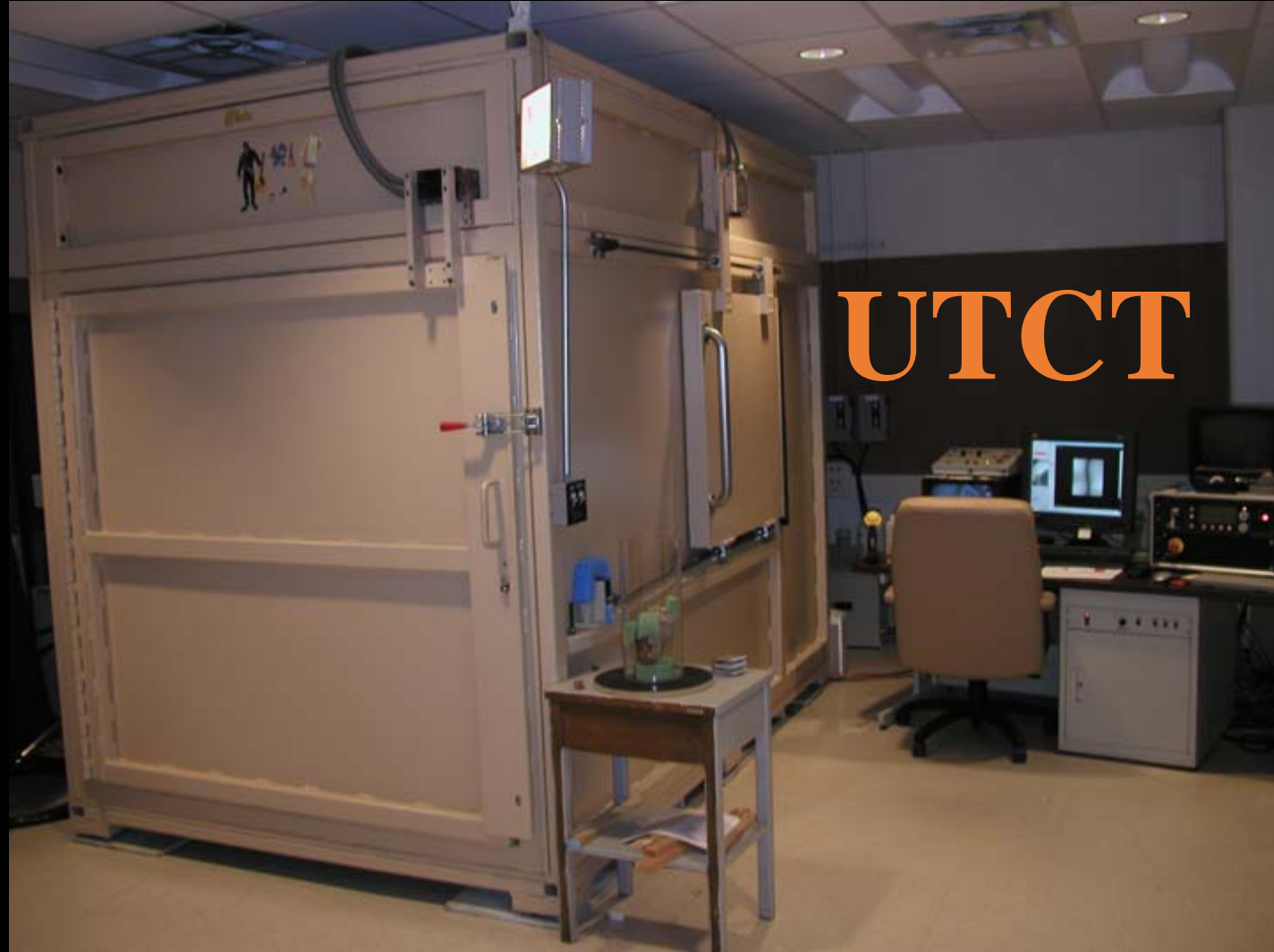
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Be careful of the things you wish for...

- 2002: planning a US tour of Lucy and Ethiopian antiquities
- I began six years of negotiations to bring Lucy to UT Austin
- 2007: exhibit opened Houston Museum of Natural Science
- 2008: permission granted!

WORLD PREMIERE
8.31.07

HOW do you relate?

LUCY'S
LEGACY

Her story *is* Your story

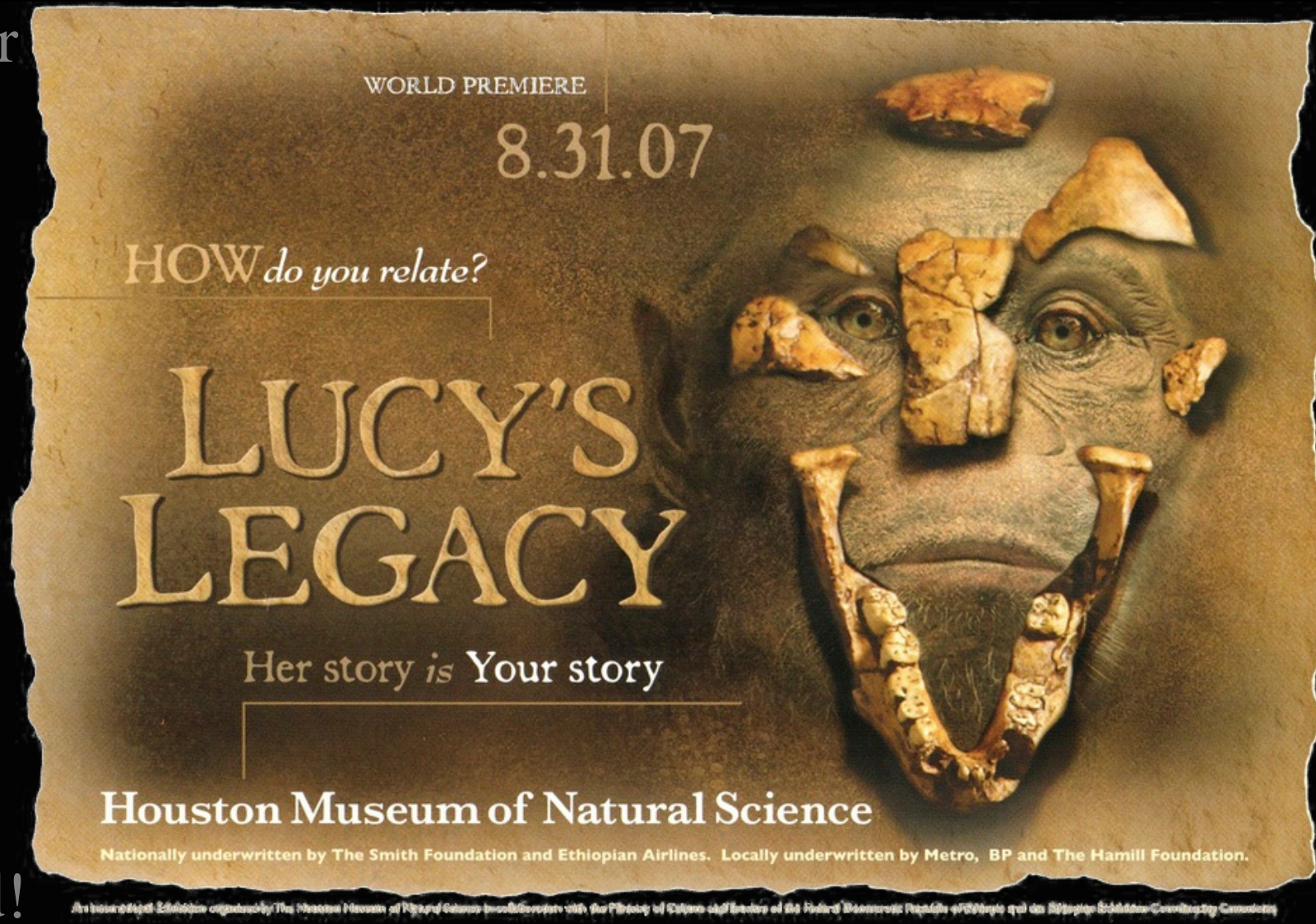
Houston Museum of Natural Science

Nationally underwritten by The Smith Foundation and Ethiopian Airlines. Locally underwritten by Metro, BP and The Hamill Foundation.

An Inaugural Edition organized by The Houston Museum of Natural Science in partnership with the Ministry of Culture and Heritage of the Federal Democratic Republic of Ethiopia and the Ethiopian Exhibition-Congress Center

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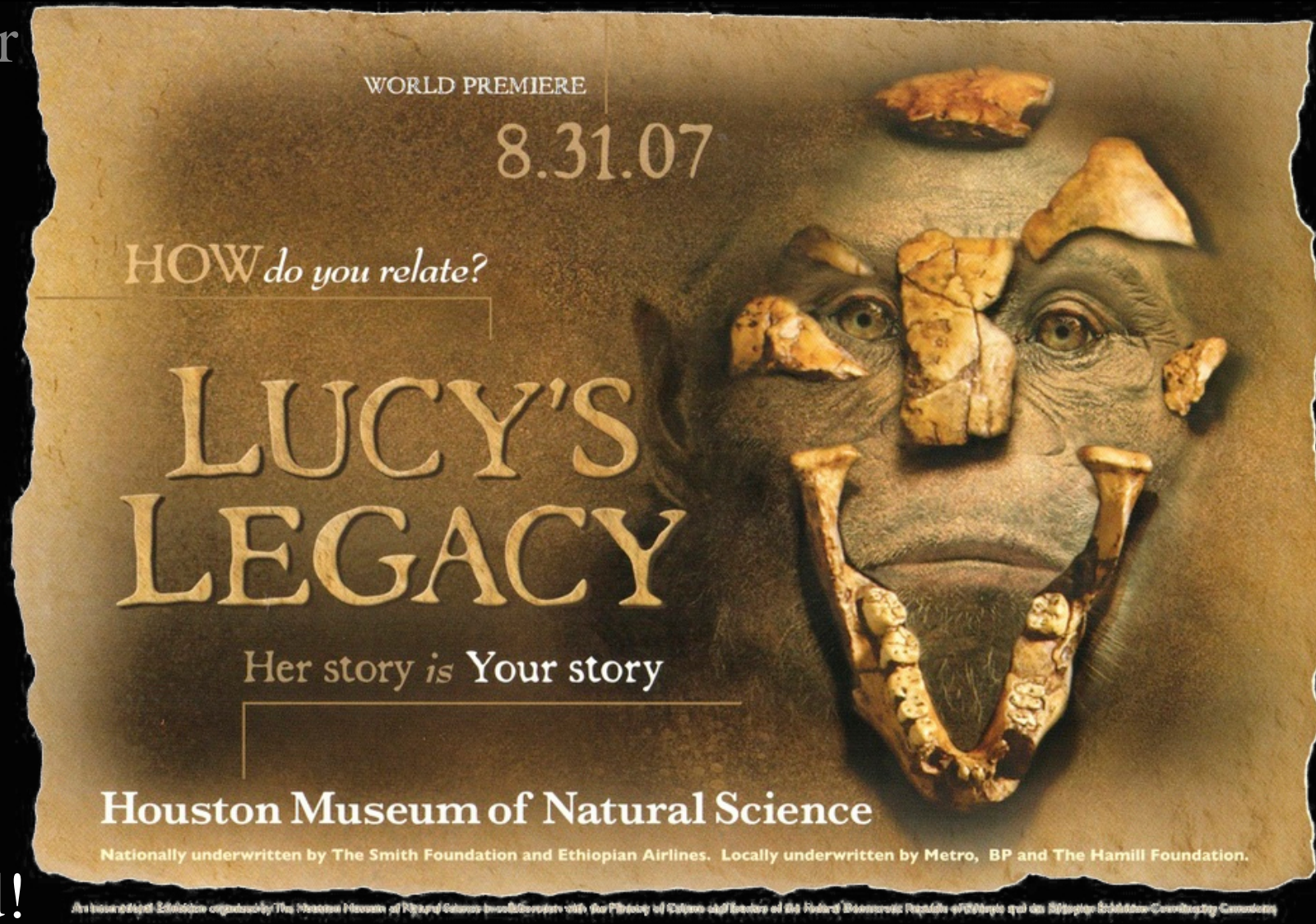
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CT scan Lucy to learn in detail how she moved

- For 11 days and 24 hours per day we scanned every fragment of Lucy's skeleton
- Only Alemu Ademassu touched the actual fossil
- Every fragment was inspected before and after scanning by Ron Harvey, an independent conservator



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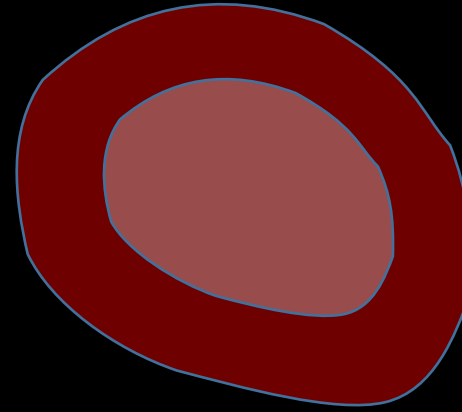
Team Lucy
 Richard A. Ketcham
 Stephen Pearce
 Lawrence Todd
 Wiley Akins
 Matthew W. Colbert
 Mulugeta Feseha
 Jessica A. Maisano
 Adrienne Witzel
 Christopher Ruff
 M. Loring Burgess



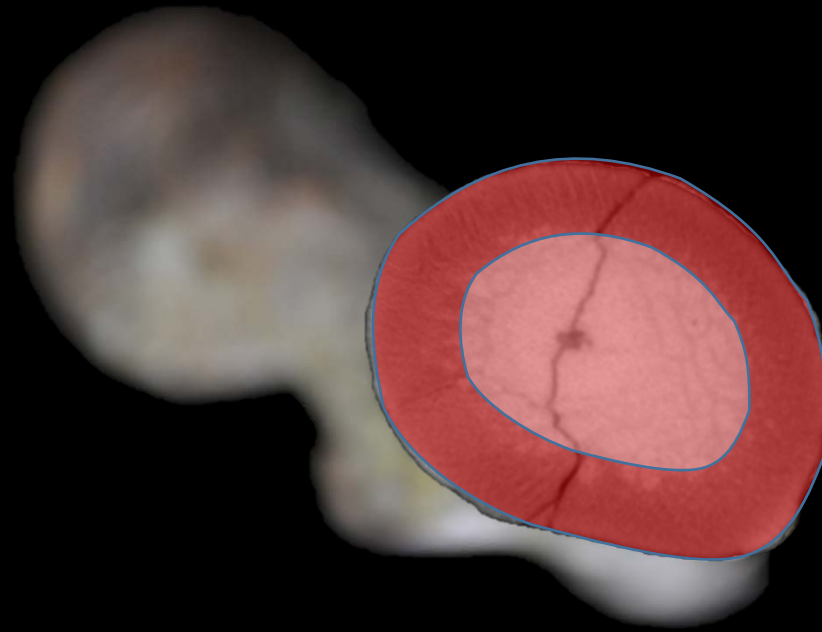
ZoeDoc

Results of high-resolution CT scanning

- Cross-section
 - Natural break in thigh bone (femur) shaft
 - High resolution CT scan



CT slice



Bone

Humerus (upper arm bone)

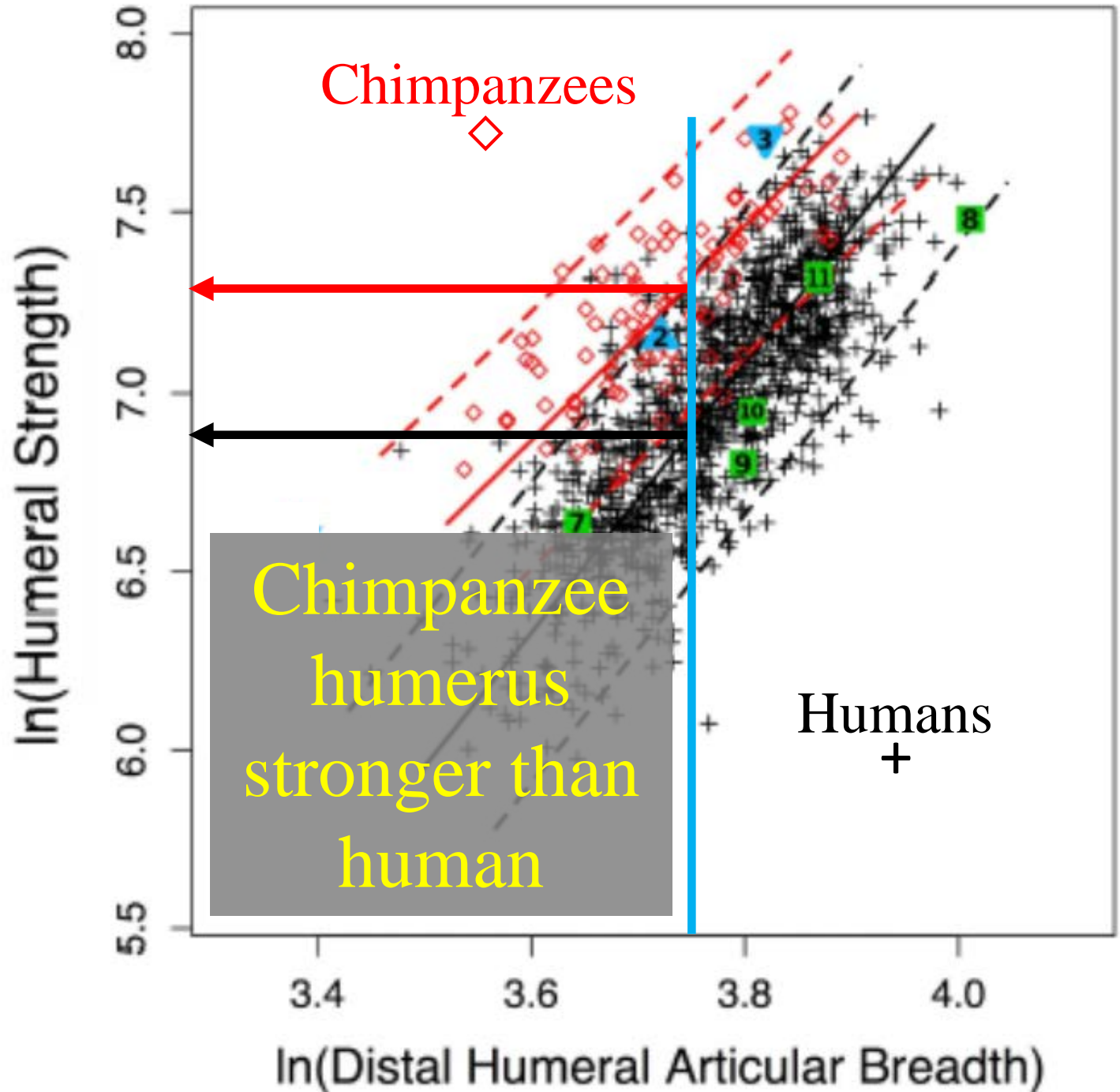


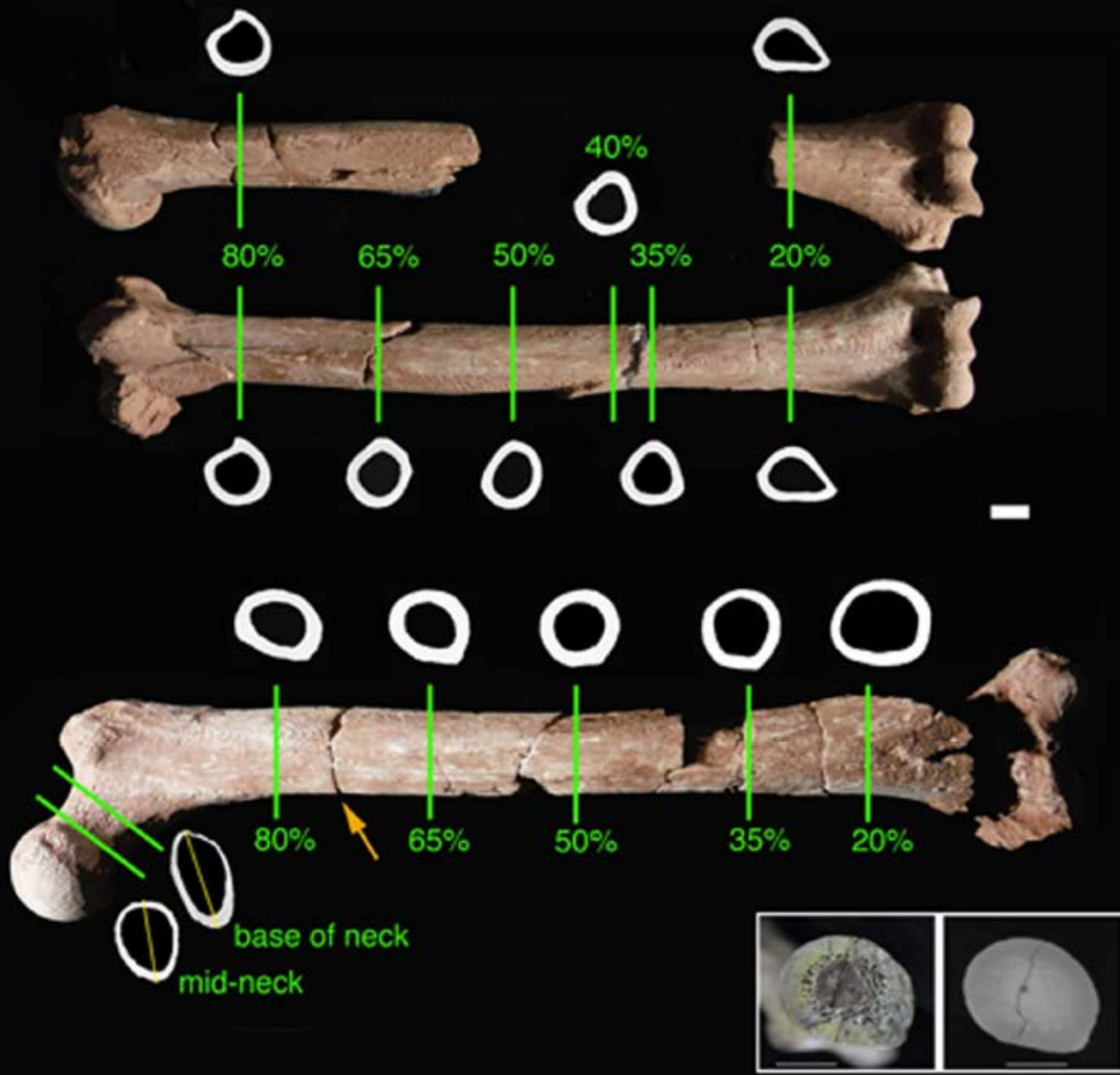
Human
(n = 1756)



Chimpanzee
(n = 98)

Bones scaled
to same length





Lucy's upper arm bone
(humerus)

- thick internal bone

- very strongly built

Limb Bone Structural Proportions and Locomotor Behavior in A.L. 288-1 ("Lucy")

Christopher B. Ruff^{1*}, M. Loring Burgess¹, Richard A. Ketcham², John Kappelman^{2,3}

PLOS ONE | DOI:10.1371/journal.pone.0166095 November 30, 2016

Fig 2. Section locations and cortical bone cross-sectional outlines for A.L. 288-1 humeri and femur, determined from CT scans. For diaphyseal sections, medial is to the left, anterior above; for femoral neck sections, anterior is to the left, superior above (medial and lateral orientations of (left) femur and left humerus reversed for consistency). Yellow lines through femoral neck sections indicate planes where superior and inferior cortical thicknesses were measured (as in [14]). Inset at lower right shows physical section (left) and CT image (right) for a natural break in the femur at about 75% of length¹, indicated with an orange arrow in the main figure. Scale bars are 10 mm.

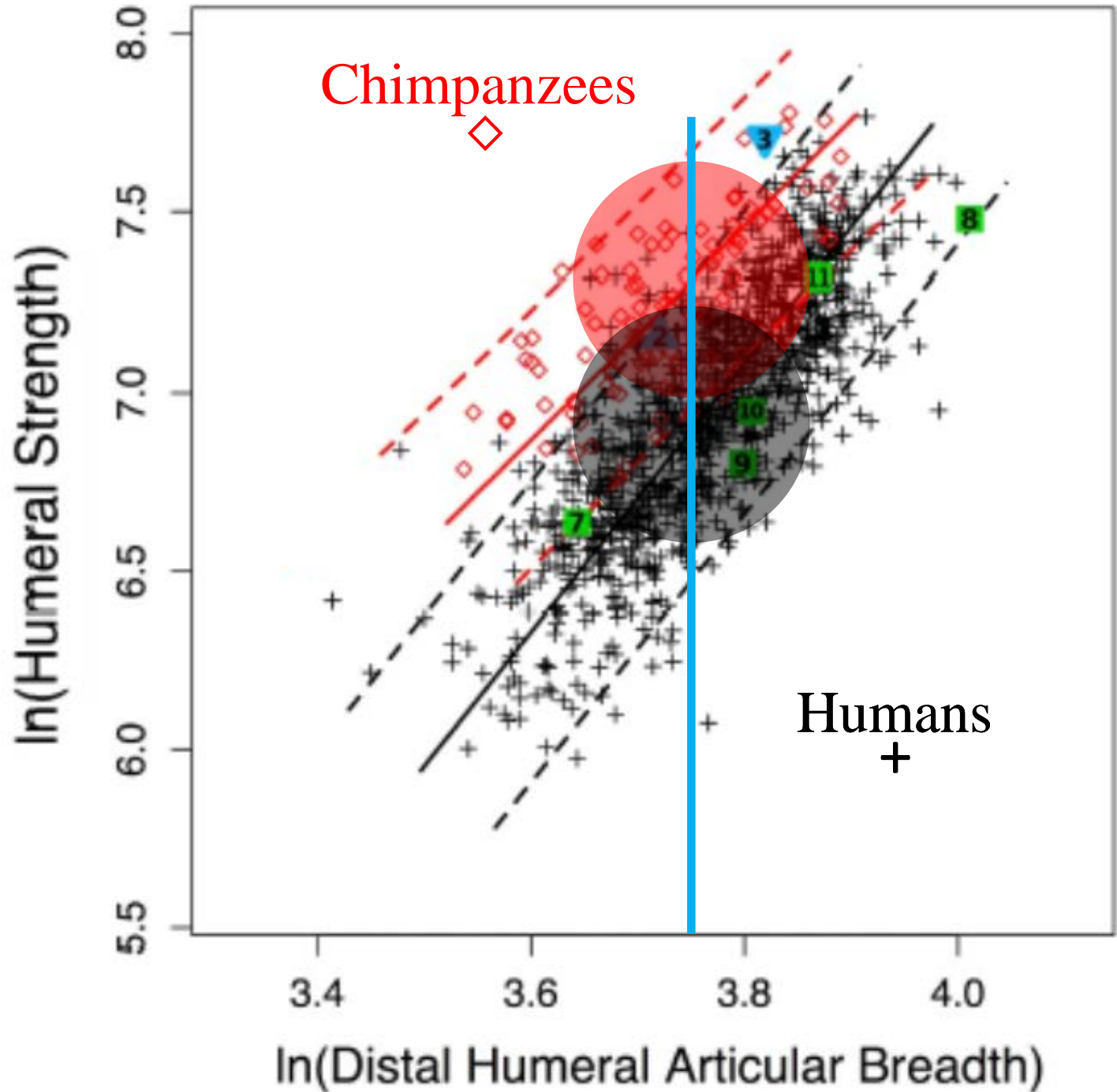
Humerus (upper arm bone)



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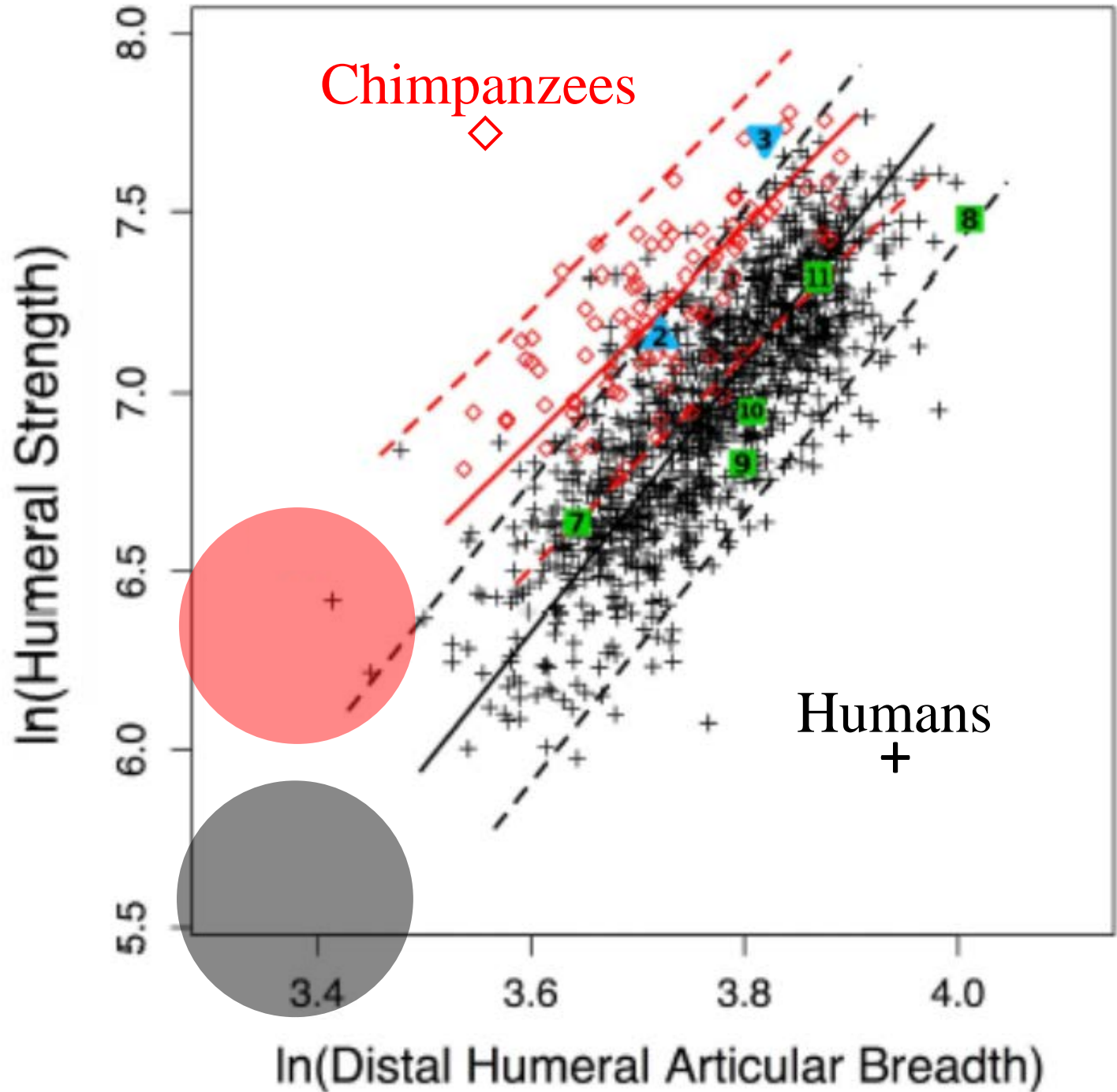
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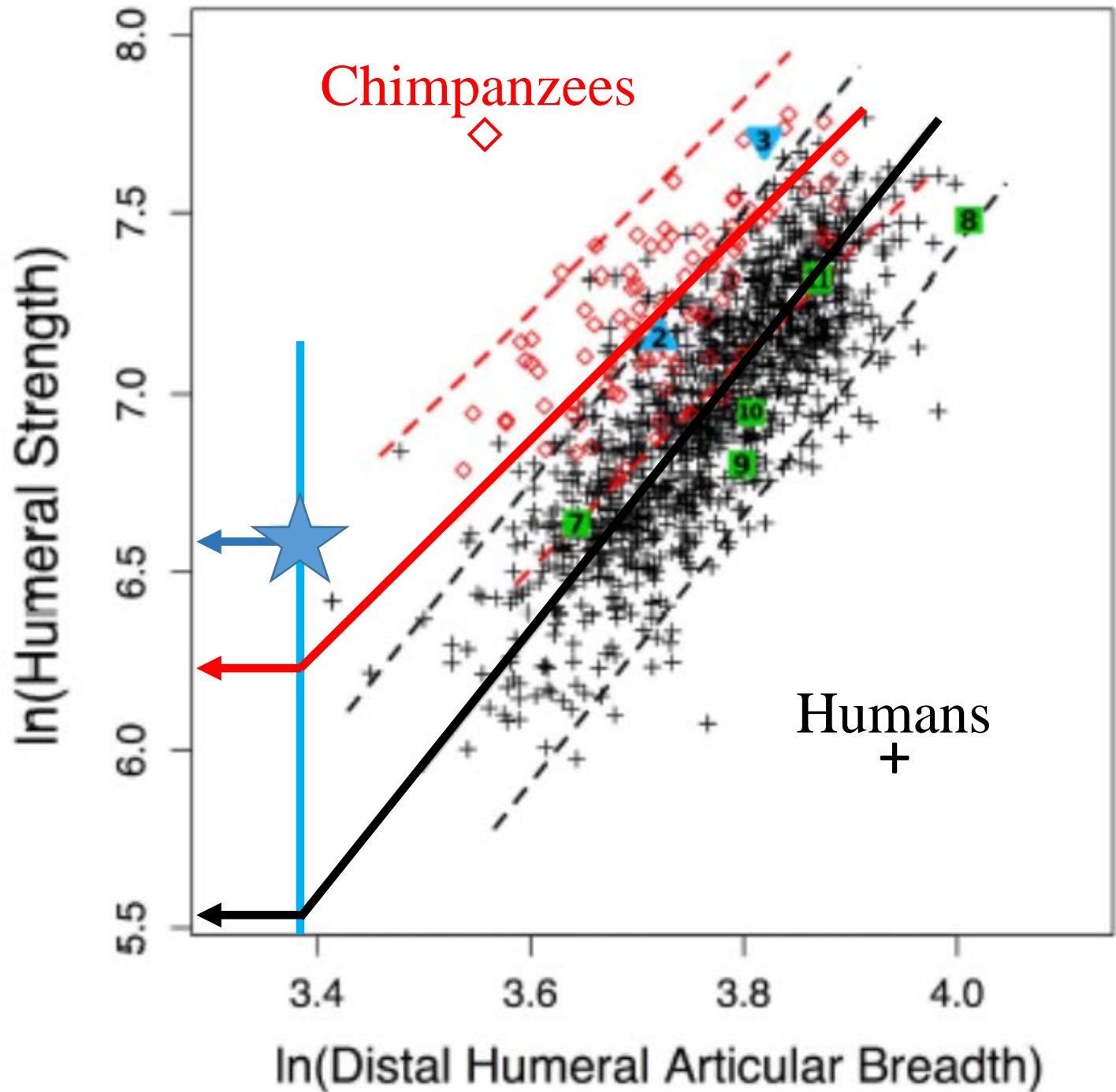
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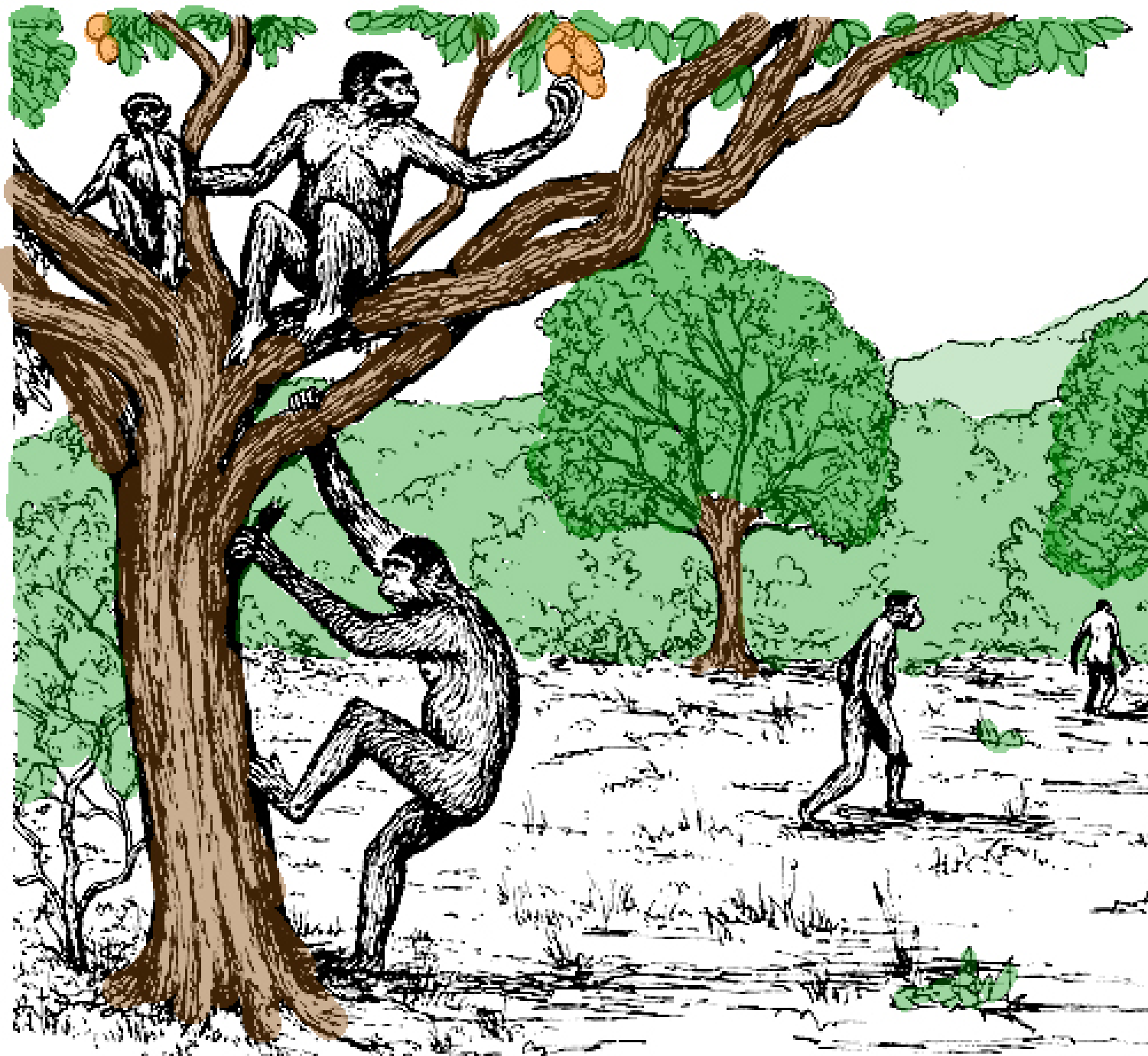


Lucy



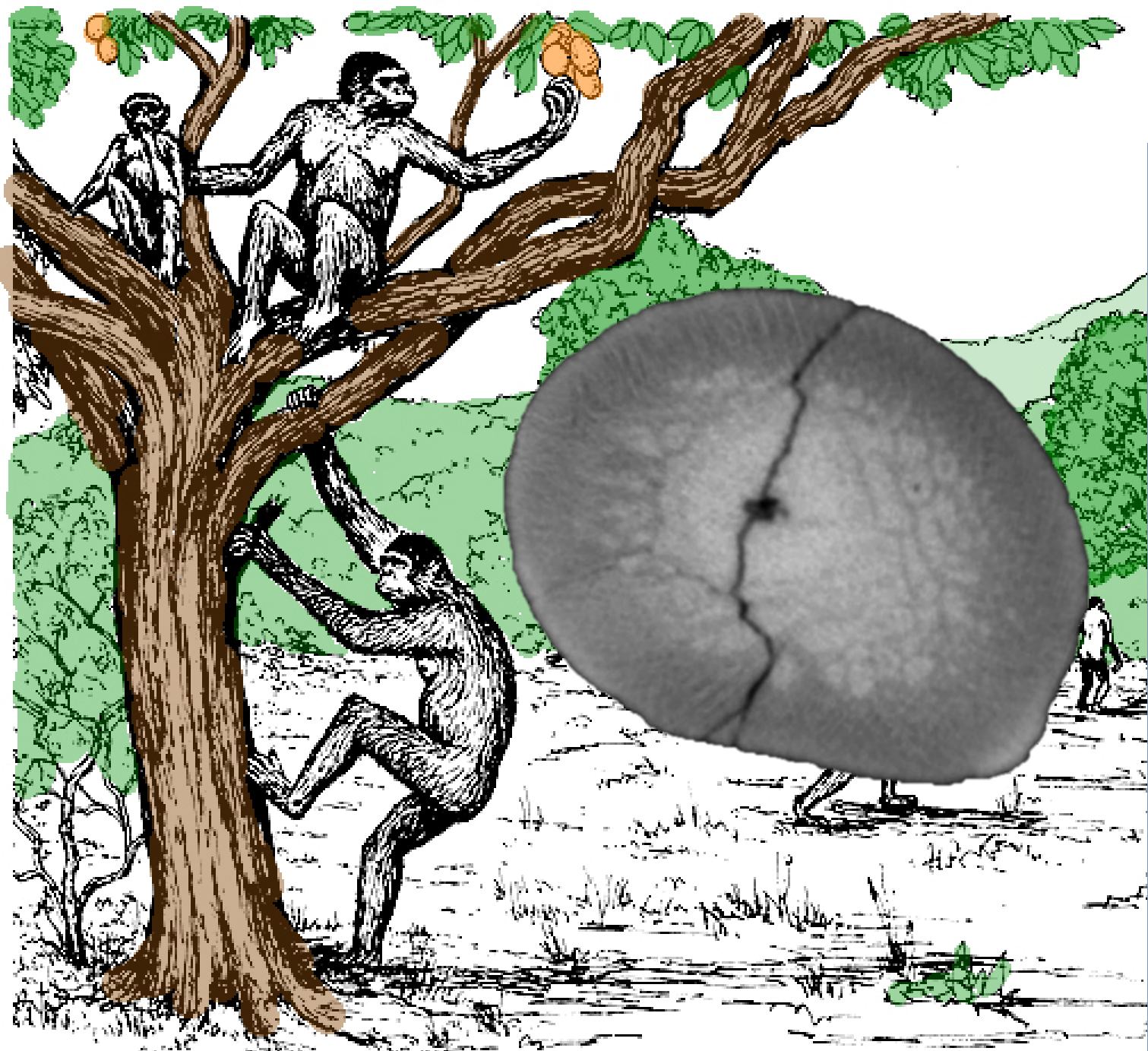
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What did we discover about Lucy?

- Agree that she walked on two legs when she on the ground (bipedal)
- CT scans show that she *also* had very strong arms and probably spent a considerable amount of time climbing in the trees, probably foraging or nesting at night



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Saturday Night Live Weekend Update:

3 Dec 2016

The image is a screenshot of the Saturday Night Live website. At the top, there is a navigation bar with the NBC peacock logo and links for SHOWS, EPISODES, SCHEDULE, NEWS & SPORTS, SHOP, APP, and LIVE. Below this is a blue header for 'SATURDAY NIGHT LIVE' with sub-links for MAIN, SKETCHES, EPISODES, PHOTOS, CAST, APP, BACKSTAGE, and SHOP. On the right side of the header, it says 'SATURDAYS 11:30/10:30c'. The main content area features a sketch with a monkey on the right and a human skeleton on the left. A red banner at the bottom of the sketch reads 'LIVED IN TREES?'. To the right of the sketch, a host is smiling. A red speech bubble is overlaid on the host, containing the text 'That girl cray'.



Anterior

Humerus



Medial



Right humerus
~Posterior view

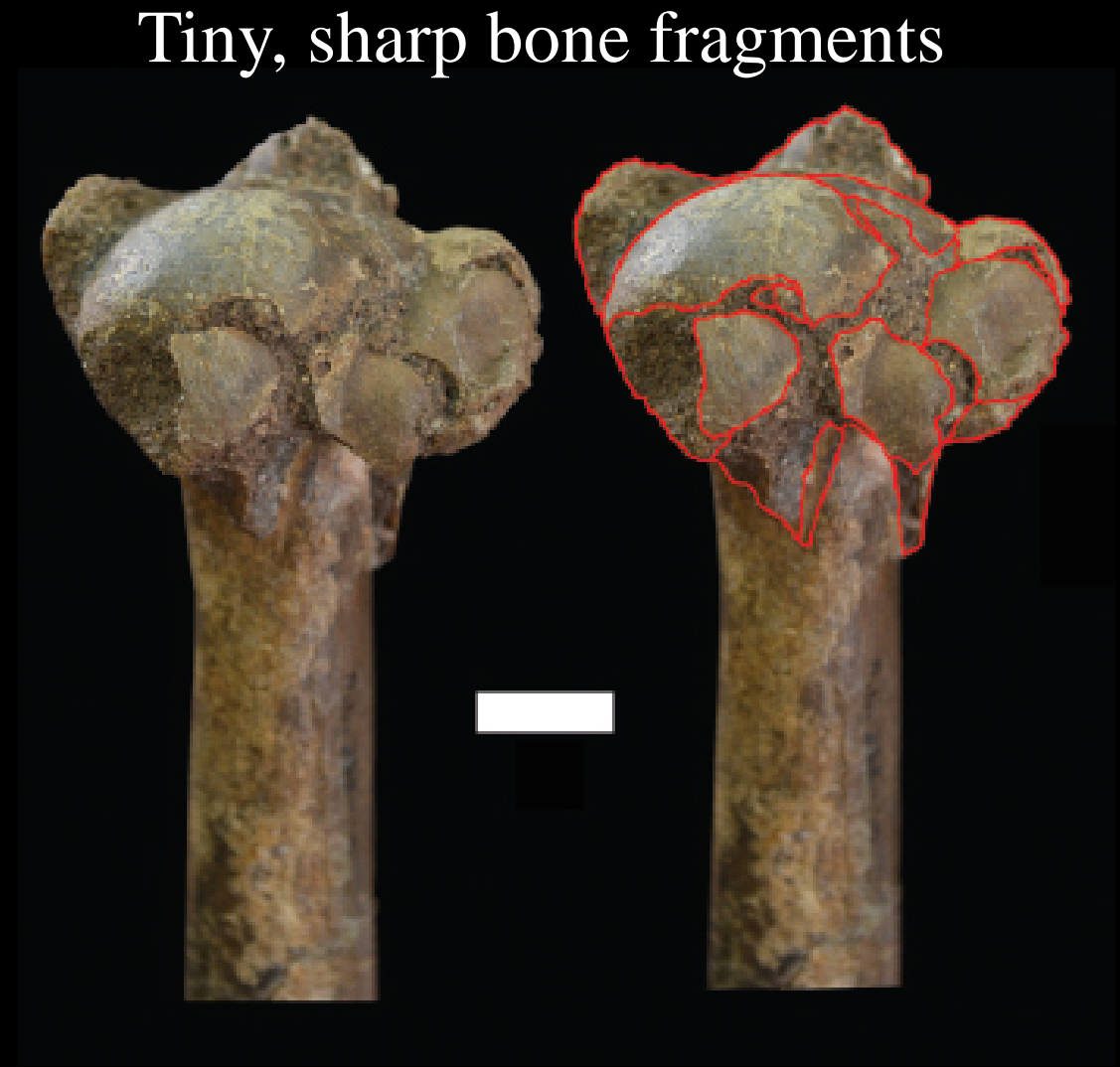


Anterior

Humerus



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Right humerus
~Posterior view

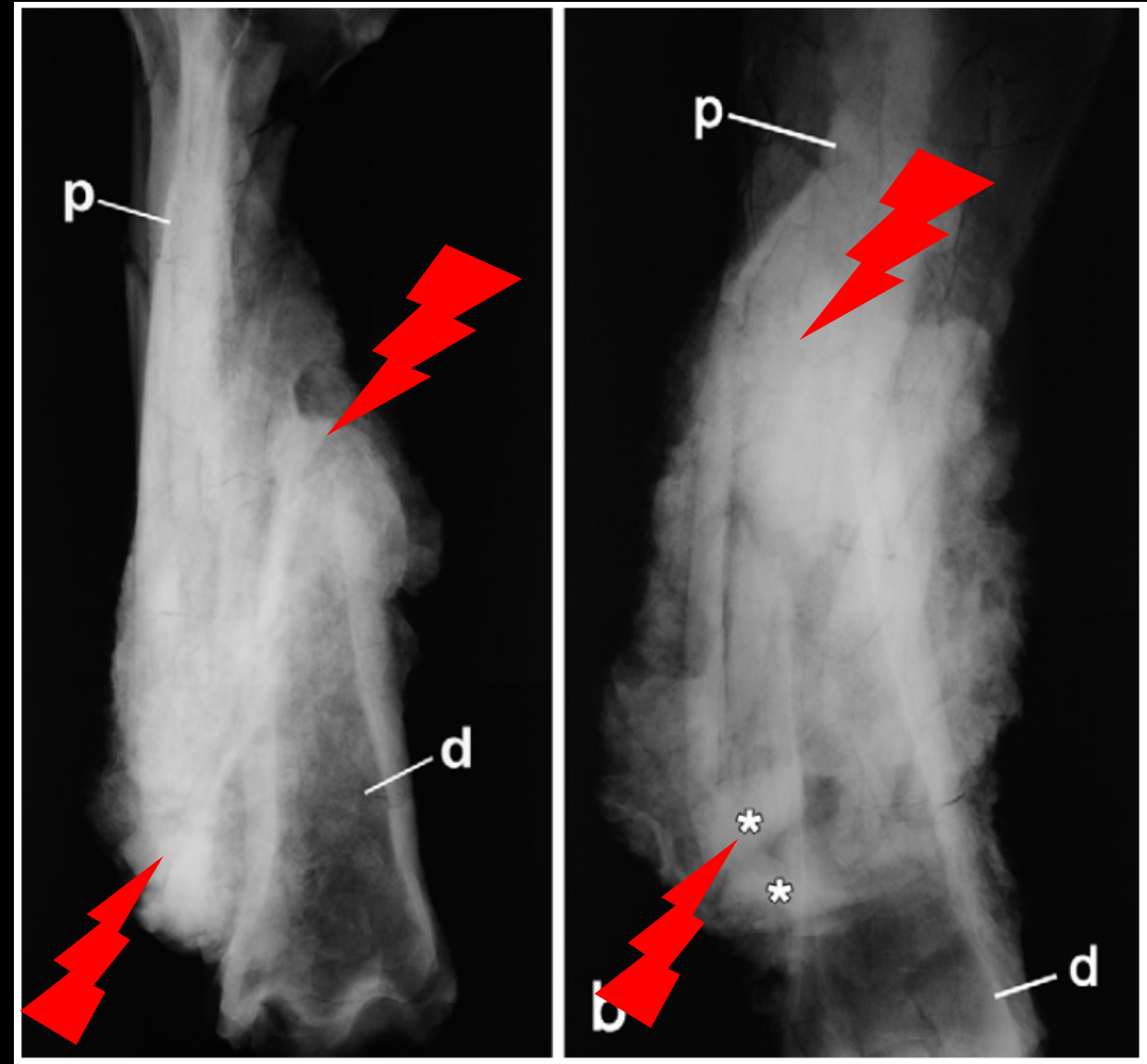


BONES

How do bones break?

Bone breakage

- **Antemortem** (“before death”): healed fracture contains fragments
- Postmortem (“after death”): often transverse to the length of the bone; dry breakage, fragments disperse on/into soil
- Perimortem (“at or near the time of death”): joint capsules and periosteum intact, fragments remain at injury site



Healed fracture (bison ~2 Ma)

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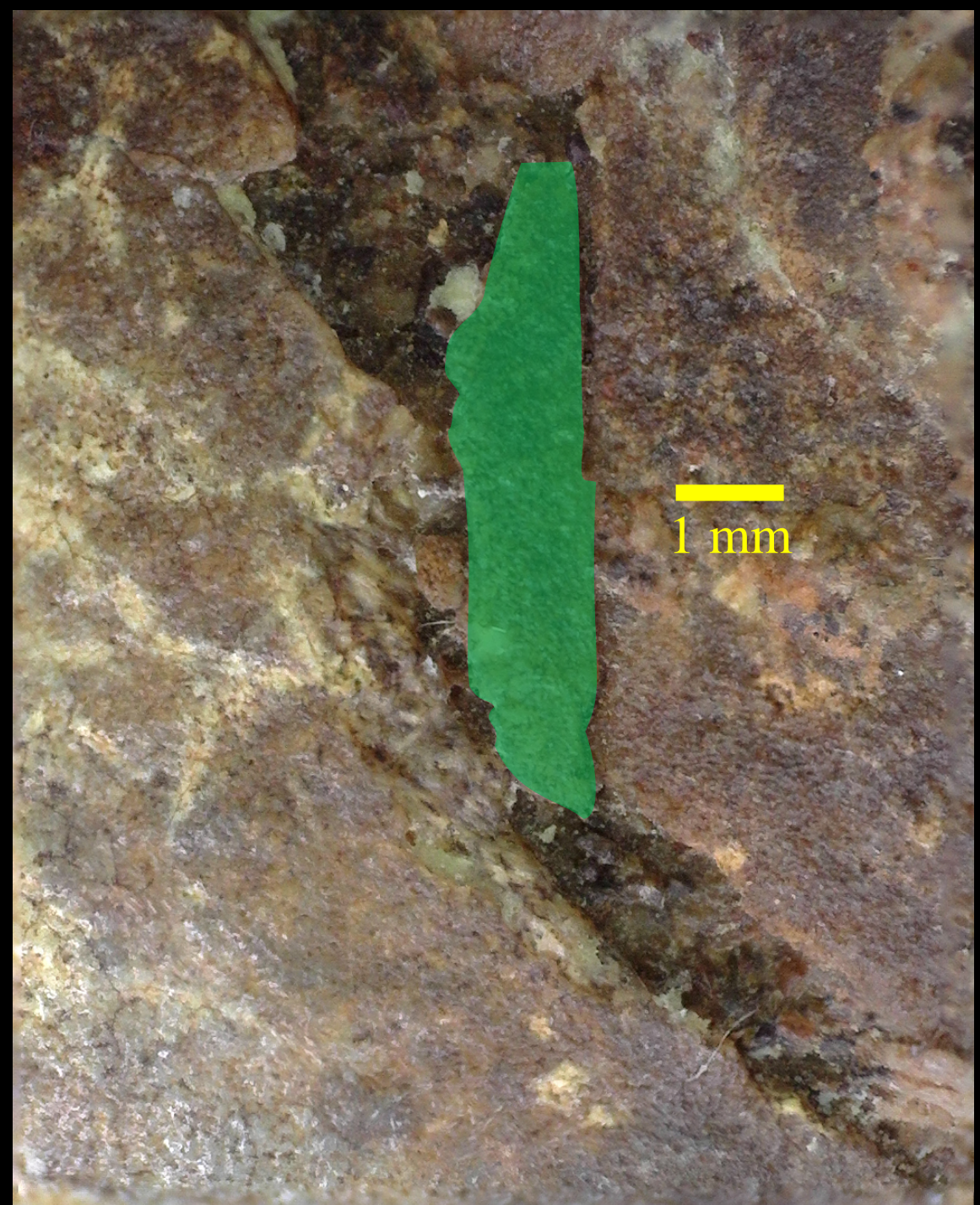
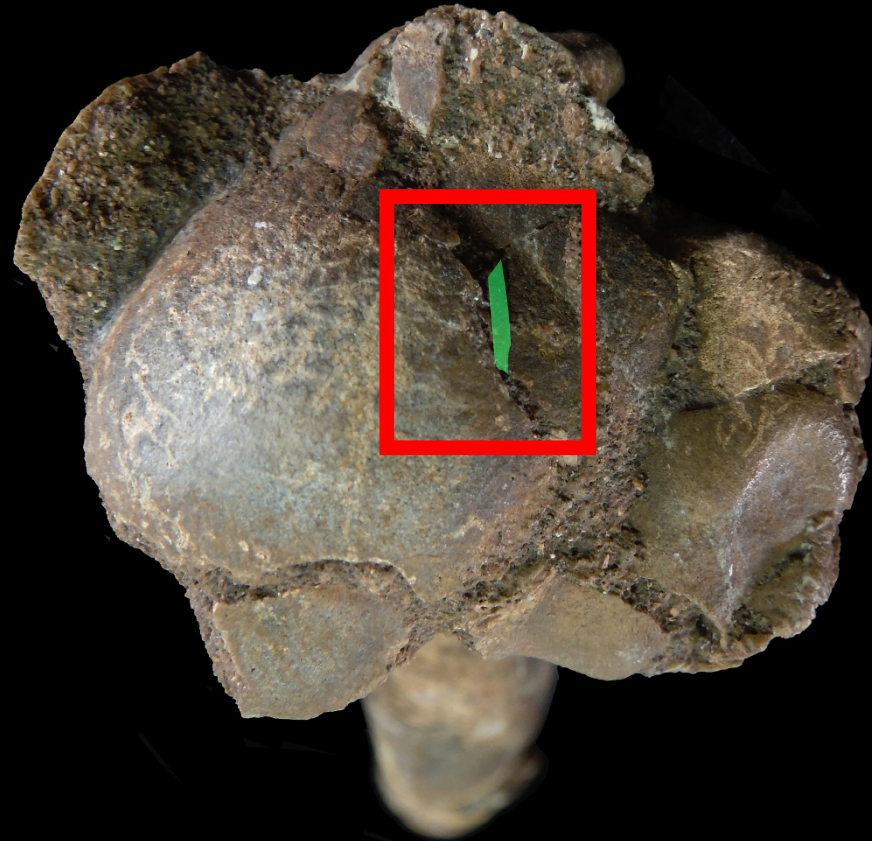
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40 m fall
from bridge,
landed on
face and
front of
body

Right proximal humerus:
numerous tiny bone fragments
and slivers (<1 x 5 mm), bone
compressed into itself



Charles Marion Russell - The Complete Works



Larry Todd



Typical postmortem breakage patterns



Odocoileus hemionus
~24 months postmortem



Fractured, but no compression

One *Tun*-dra of force

Typical postmortem breakage patterns



Multiple fragments & slivers preserved
in situ: what sort of fracture is it?



Compressive
perimortem
fracture?

Portion of
convex
curvature
of head
preserved



Right humerus
~posterior, stereo view

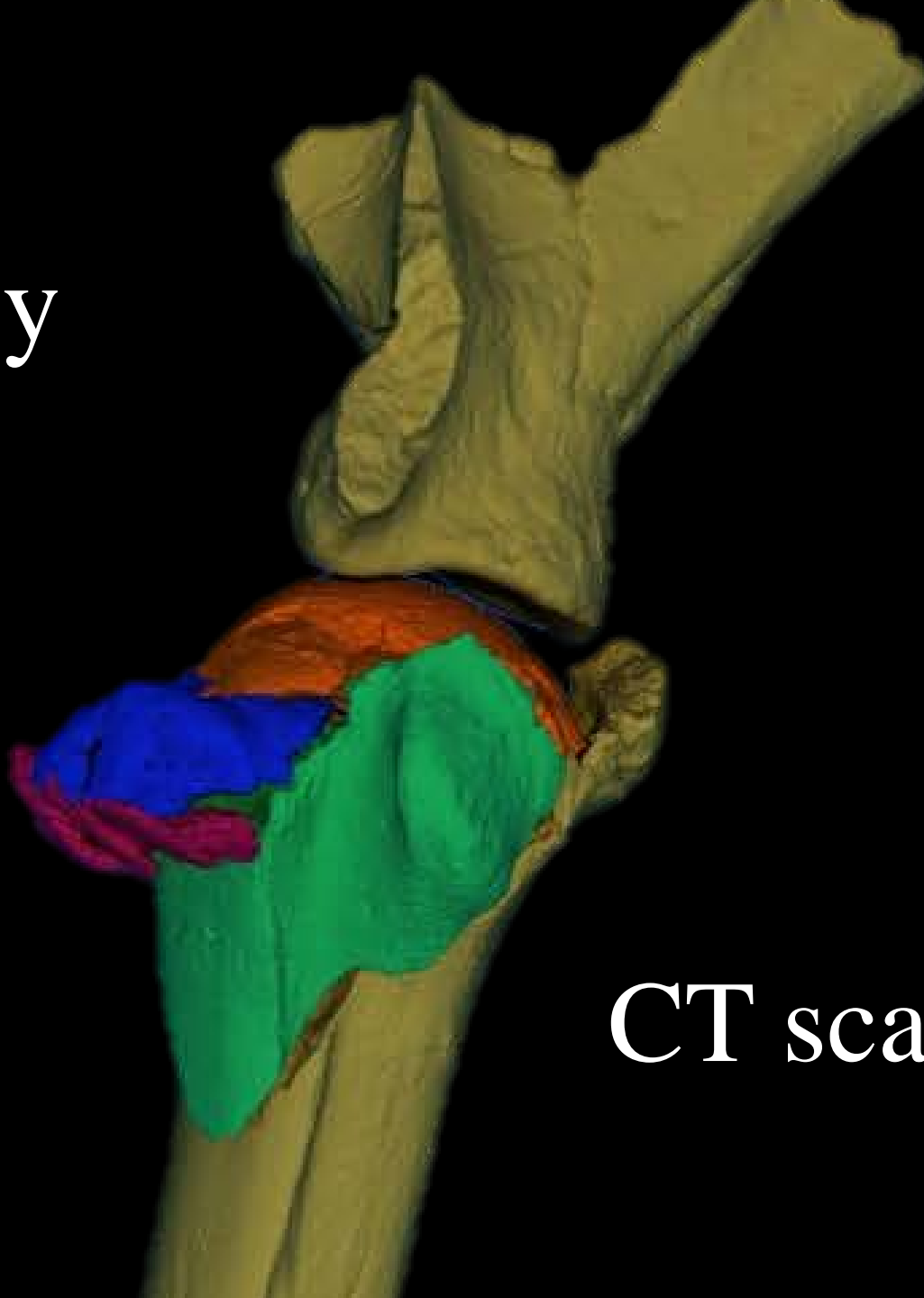
Four-part proximal humerus fracture:

Shoulder joint fracture:
impact following a fall – known
as a ***vertical deceleration event*** –
drives joint of shoulder blade
(glenoid) into the upper arm joint
(humeral head)

a unique signature of injury



Lucy



Modern human
fall victim



CT scans

Lucy proximal humerus:
supersized
human-scale 3D printout

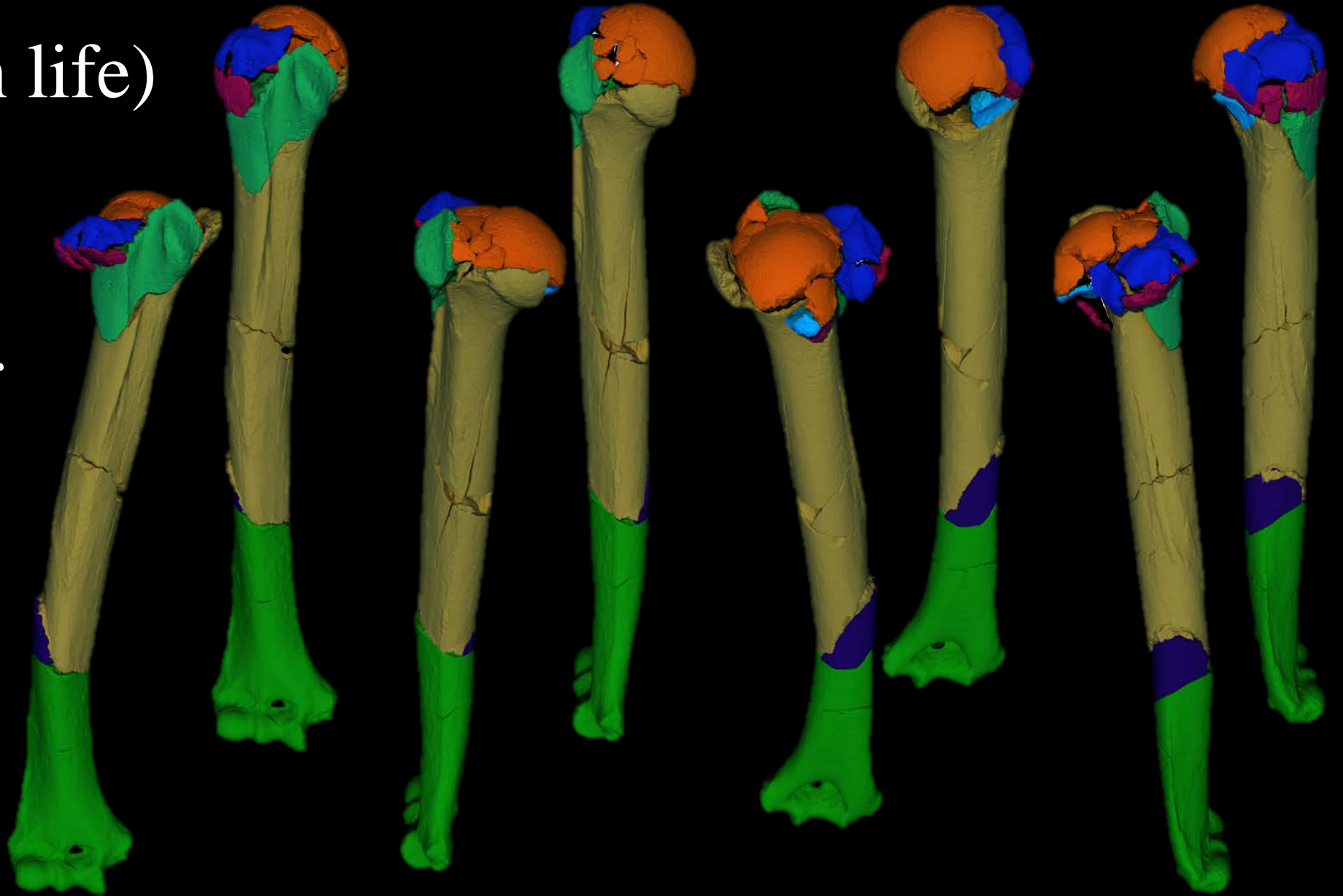
Dr. Stephen Pearce
Austin Bone and Joint Clinic
Austin, TX

Dr. Tom Helpenstell & Associates
Olympia Orthopaedic Associates, Seattle, WA



Before (in life)

After
(post-injury)

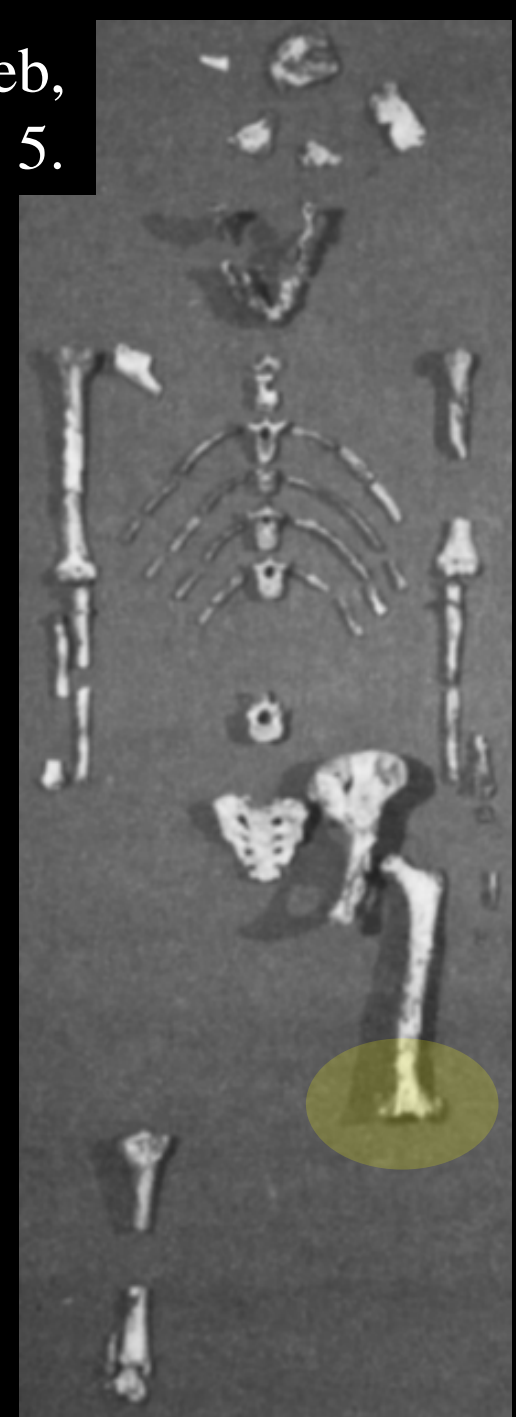
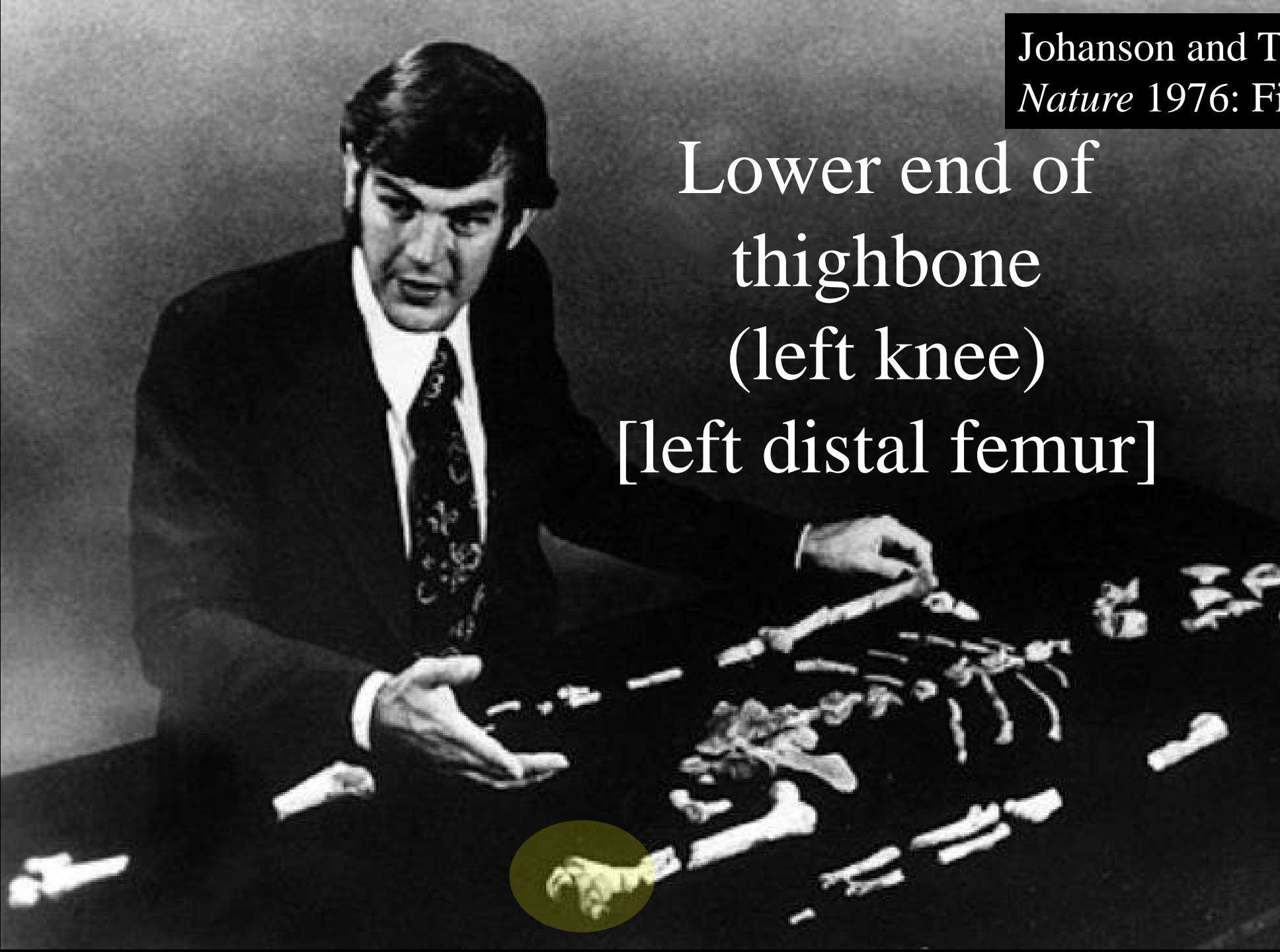


CT segmentation & reconstruction of right proximal humerus



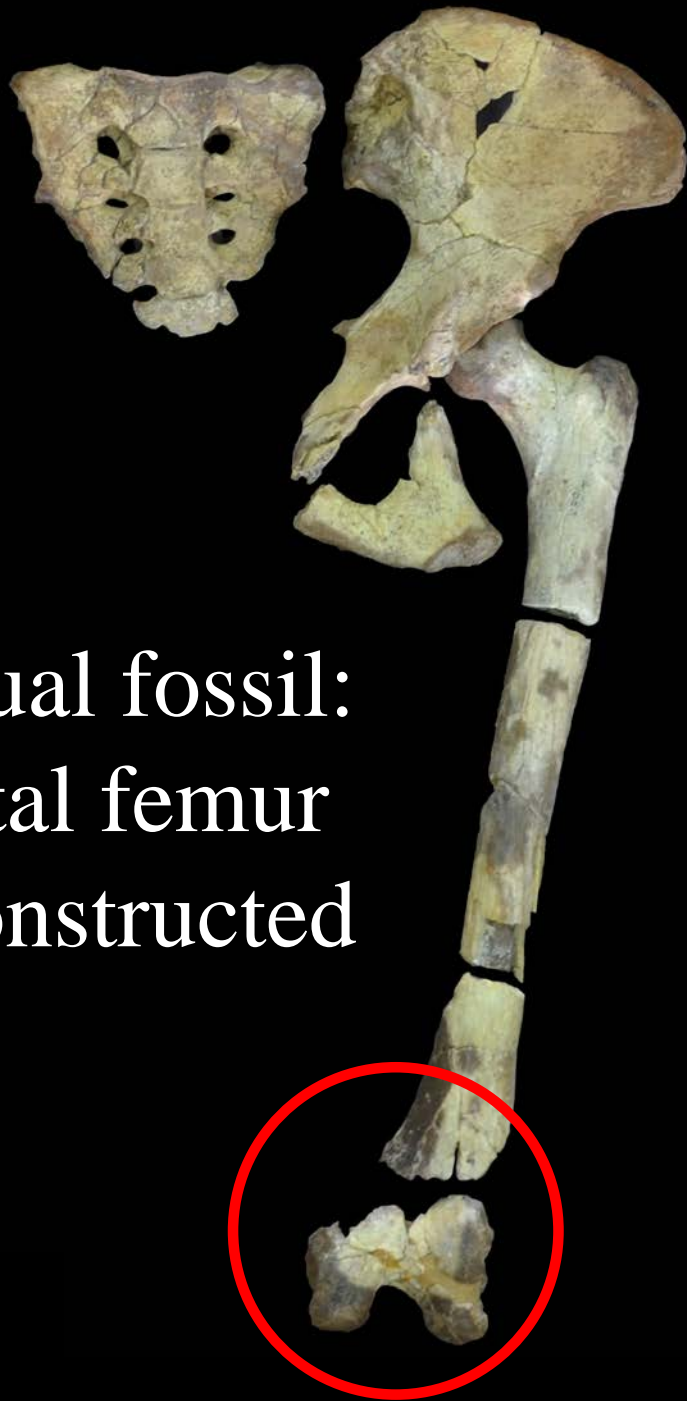
Johanson and Taieb,
Nature 1976: Fig. 5.

Lower end of
thighbone
(left knee)
[left distal femur]

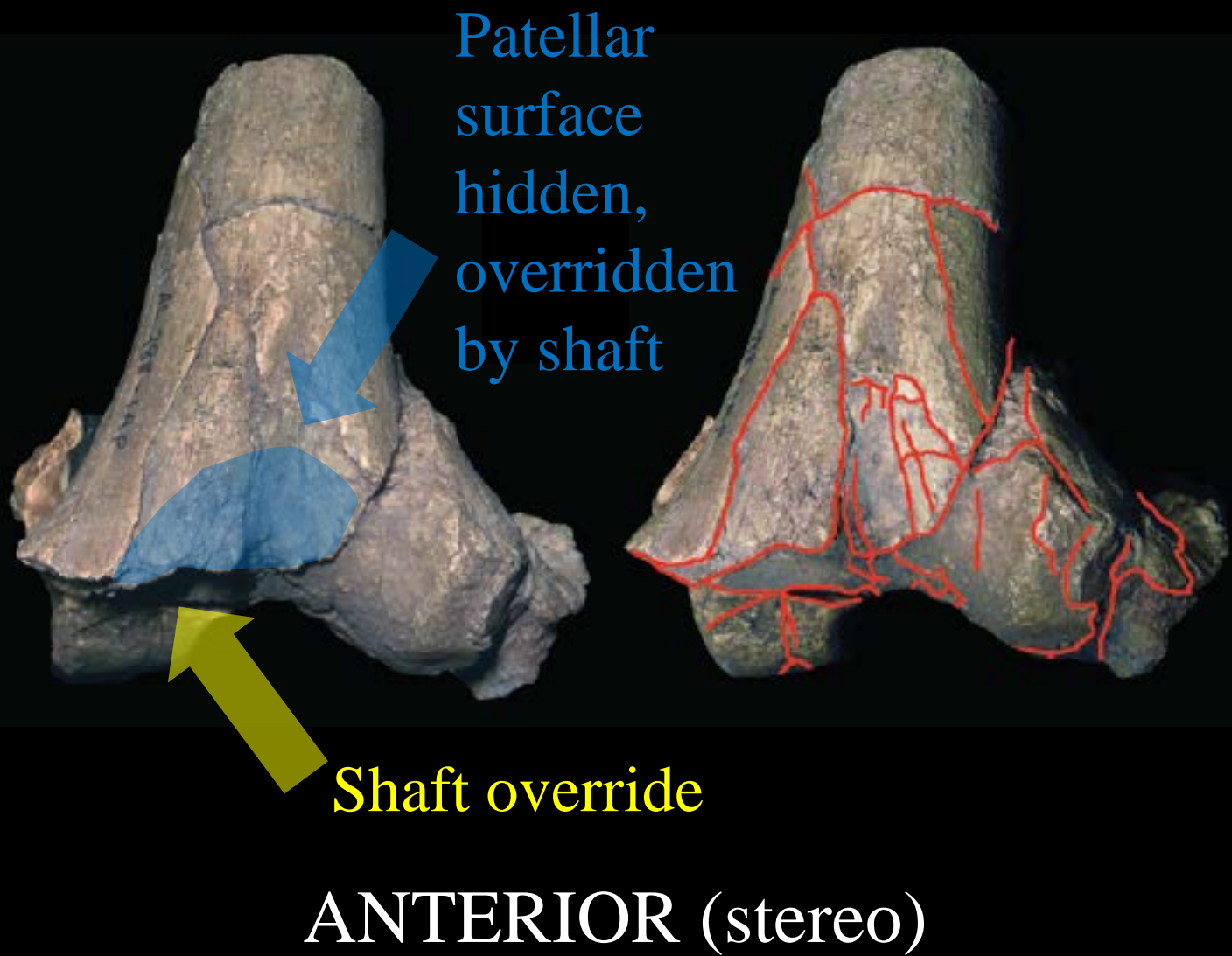


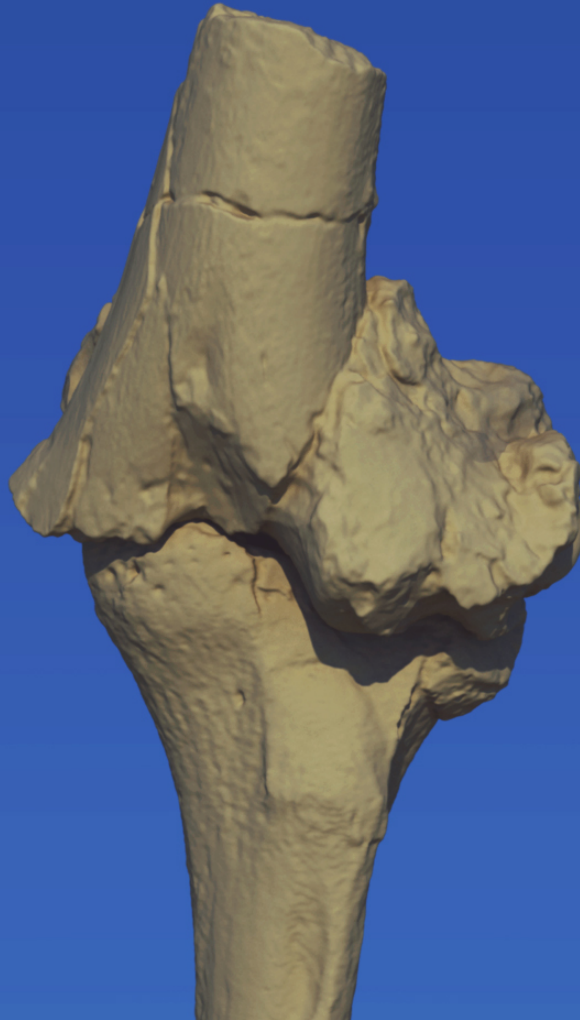


Actual fossil:
distal femur
reconstructed



Cleveland casts + UT medial condyle (not to same scale)





Compressive fracture by impact between femur and tibia dislocates the knee and drives it into the shaft.

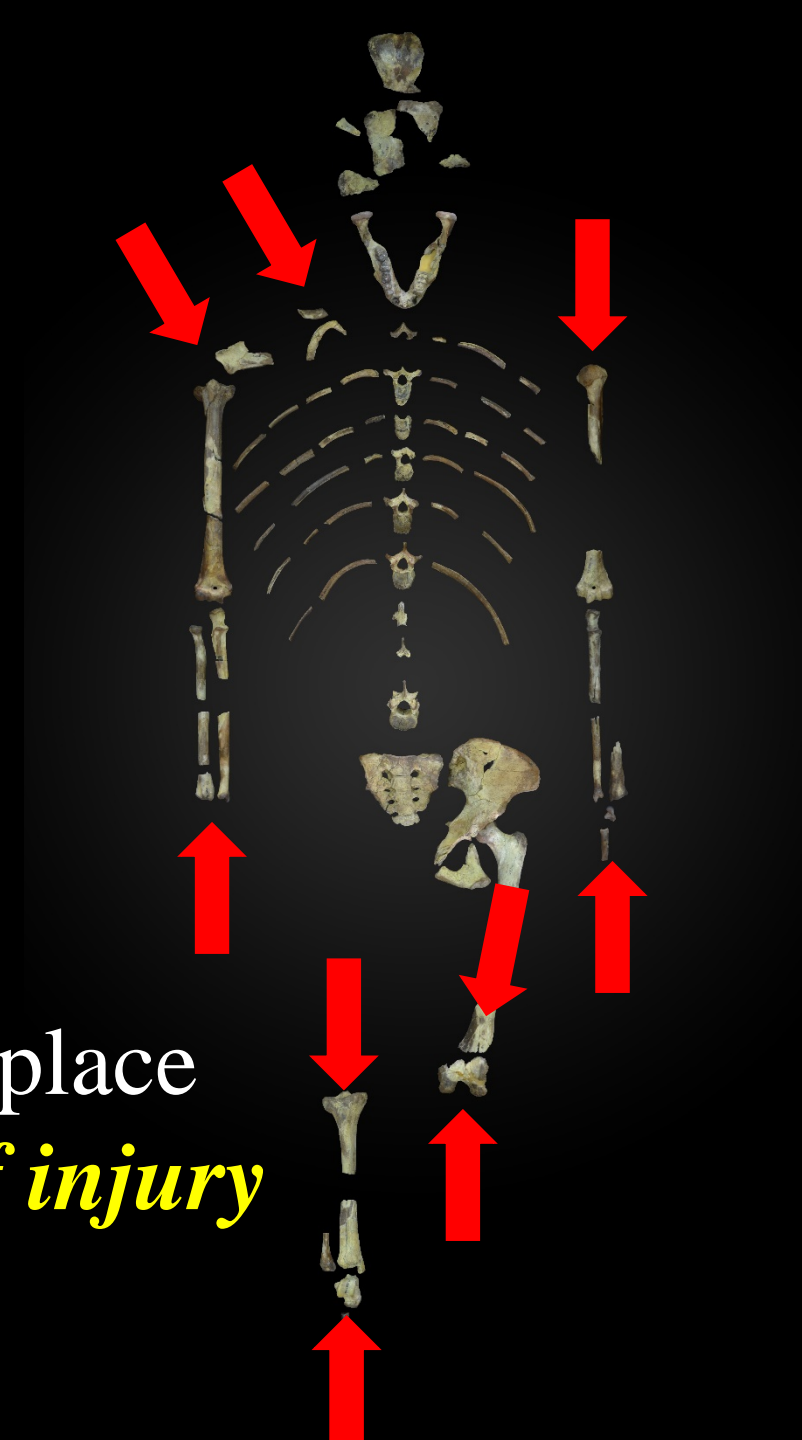
X-ray of
compressive
fracture of knee
produced by
impact
following a fall



Bone-to-bone compressive fractures are preserved at several major joints:

- Right (severe) and left shoulders
- Clavicle & first rib
- Right wrist
- Left knee
- Right knee
- Right ankle

Small, sharp bone fragments remaining at place of fracture along with *unique signature of injury* strongly suggest *perimortem* fractures



If **perimortem**, several mechanisms produce bone fractures:

- Lightning strikes or seizure-generated fractures (violent tetanic muscle contractions)
- Blunt force trauma by impact with debris during floods
- Injuries and fractures caused by animals



[Link](#)

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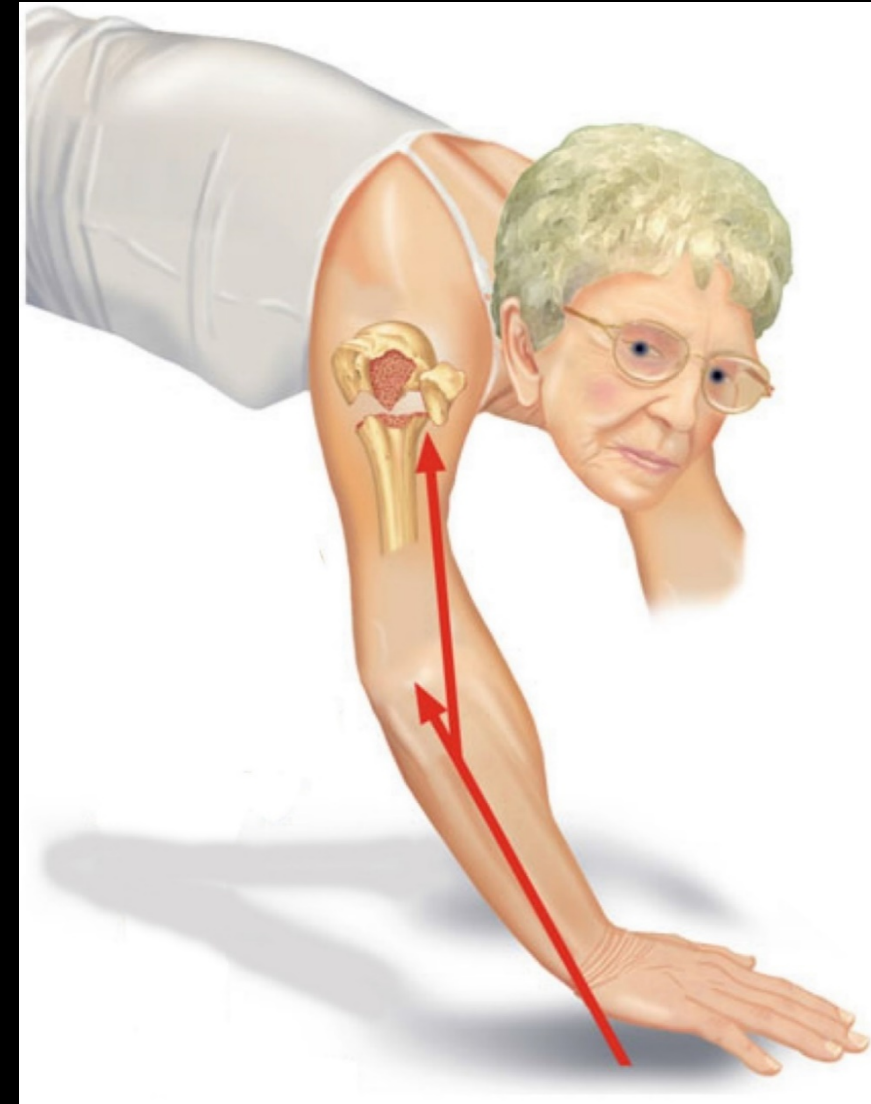
**Yellowstone bison
and visitor**

If **perimortem**, several mechanisms produce bone fractures:

High energy vertical deceleration event
(common in modern cases, documented by X-rays and CT scans shown earlier)

A unique signature of injury:

Lucy was conscious when she hit the ground, and stretched out her arms to try to break her fall



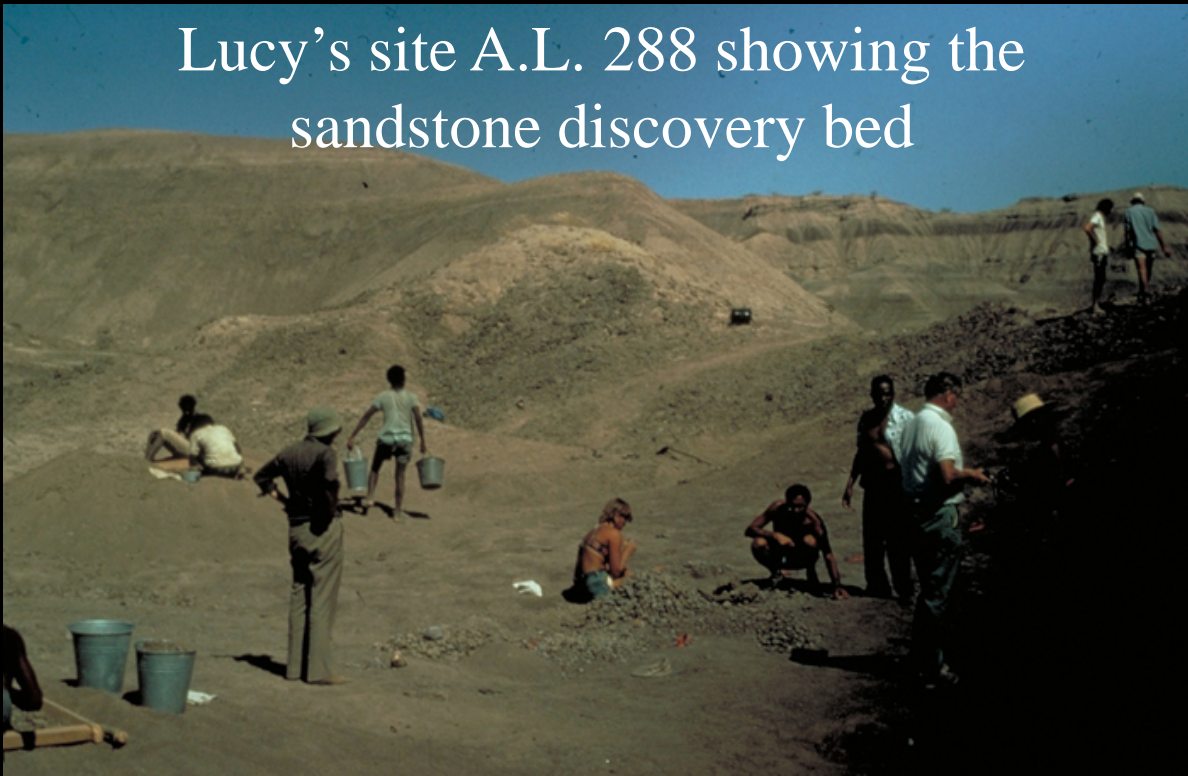
Does knowing where was Lucy discovered help us to untangle the mystery of her death?

Thin (~0.5 m) sandstone deposited by a small stream with turtle and crocodile eggshells, crab claws, and rodent skulls

Located on low-relief area of distal floodplain near lake

Stream bank probably too low for a fall to produce high energy fractures

Lucy's site A.L. 288 showing the sandstone discovery bed



Modern Awash River and small streams



<https://morenewsfromafar.wordpress.com/2012/02/27/awash-river-valley-afar-oasis/>

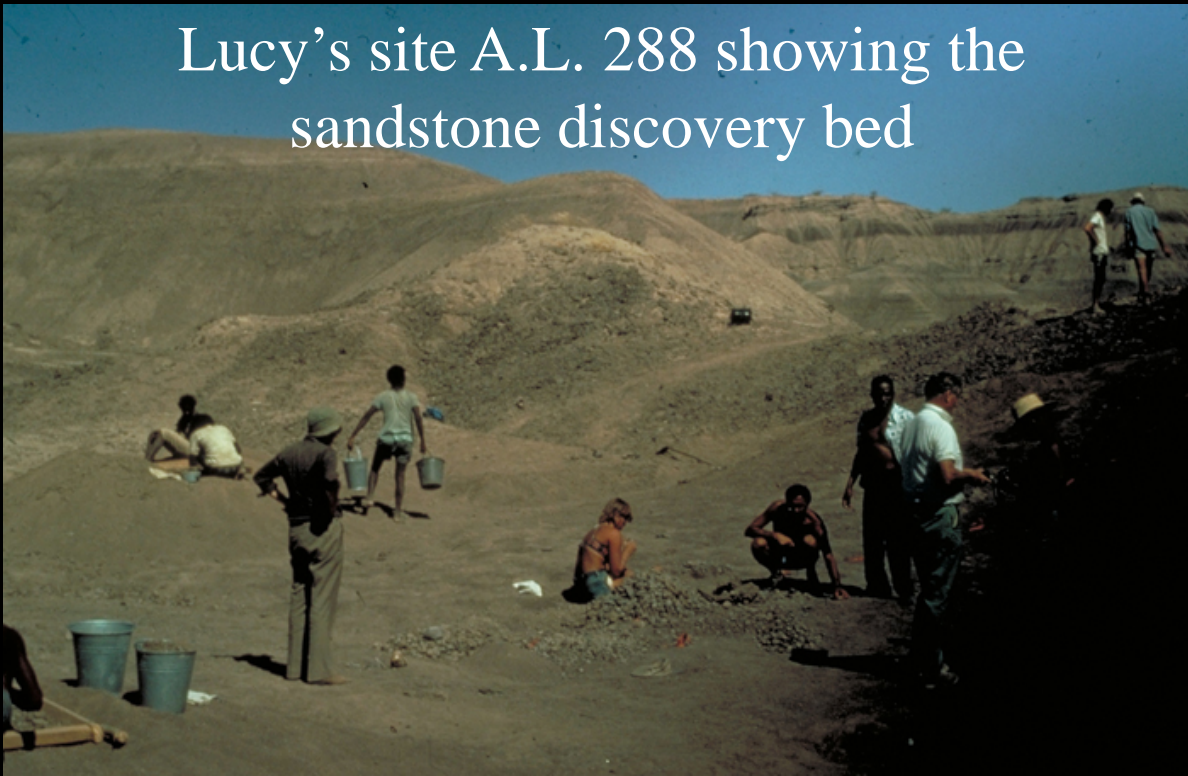
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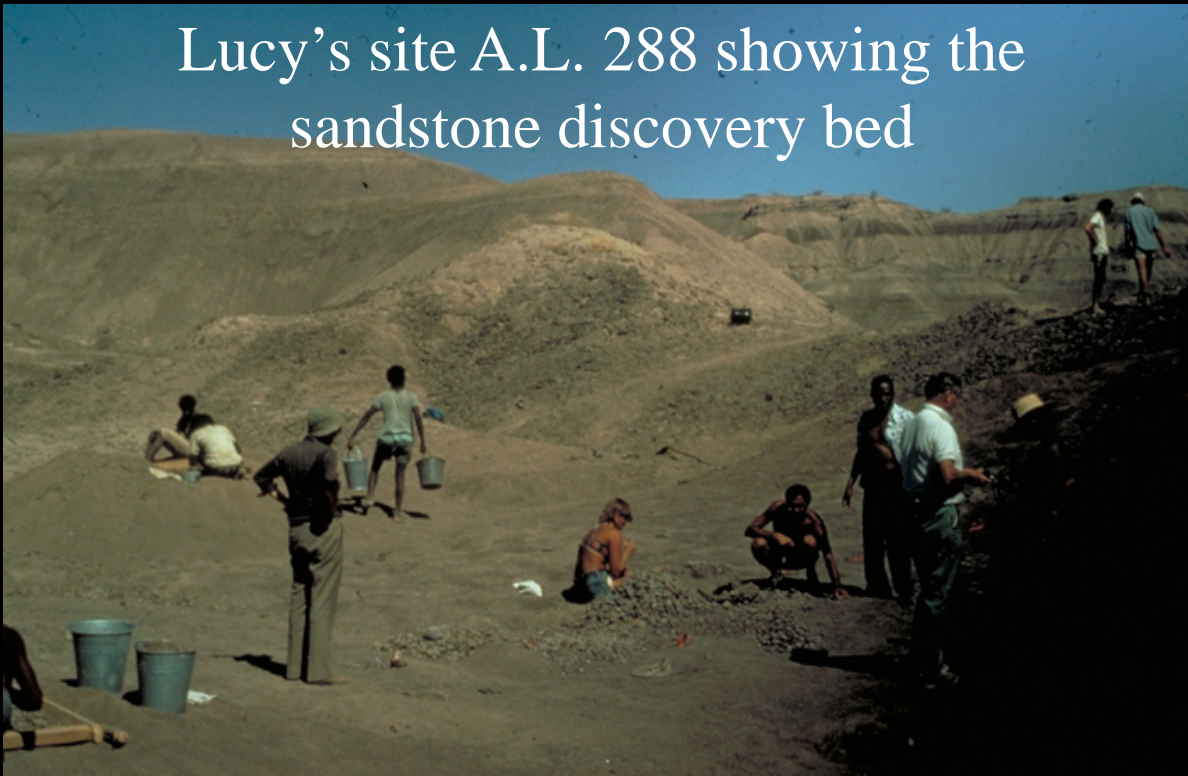
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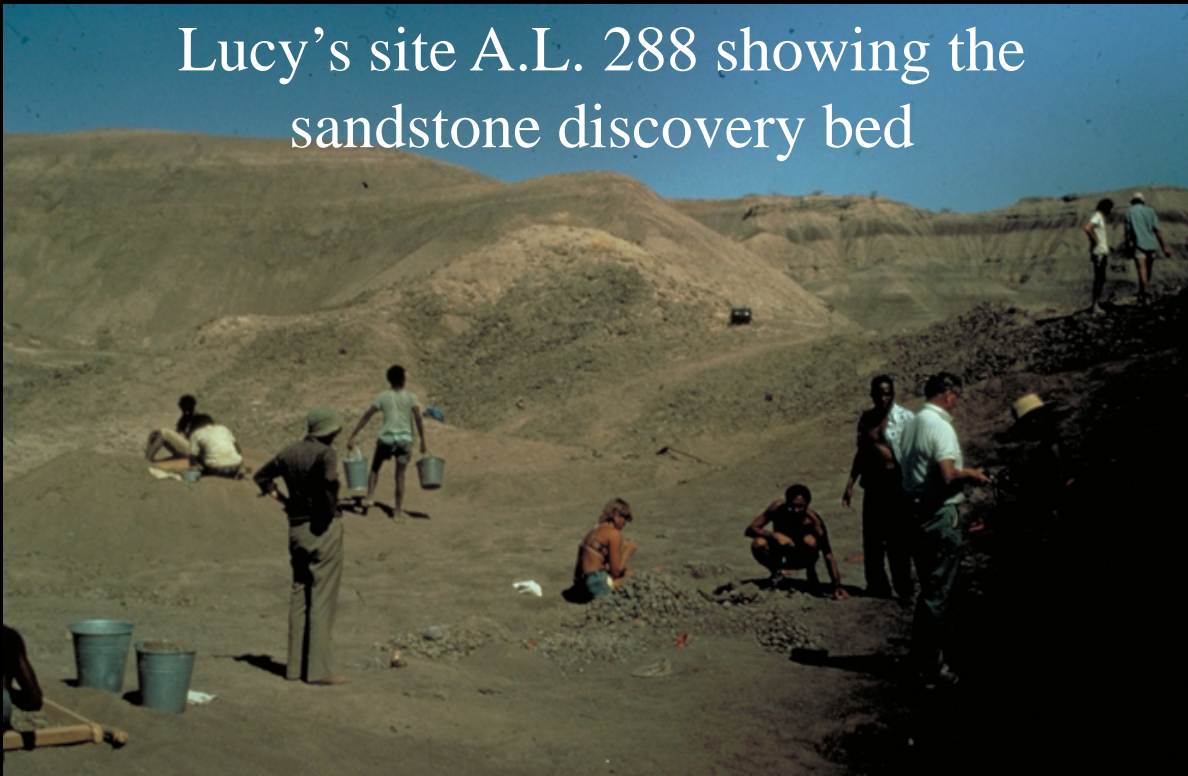
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Trees!!

Given Lucy's small size (~27 kg, ~1.1 meters in height), we propose that she nested in trees at night to avoid predators, and also climbed trees to forage.

Chimpanzee average night nest height is nearly 14 m.

A fall from this height produces an impact velocity of ~60 km/hr, sufficient to produce the fractures seen in her skeleton.



Chimpanzee tree night nest
(Smithsonian image)

We hypothesize that Lucy suffered perimortem fractures as she fell out of a tree from a considerable height.

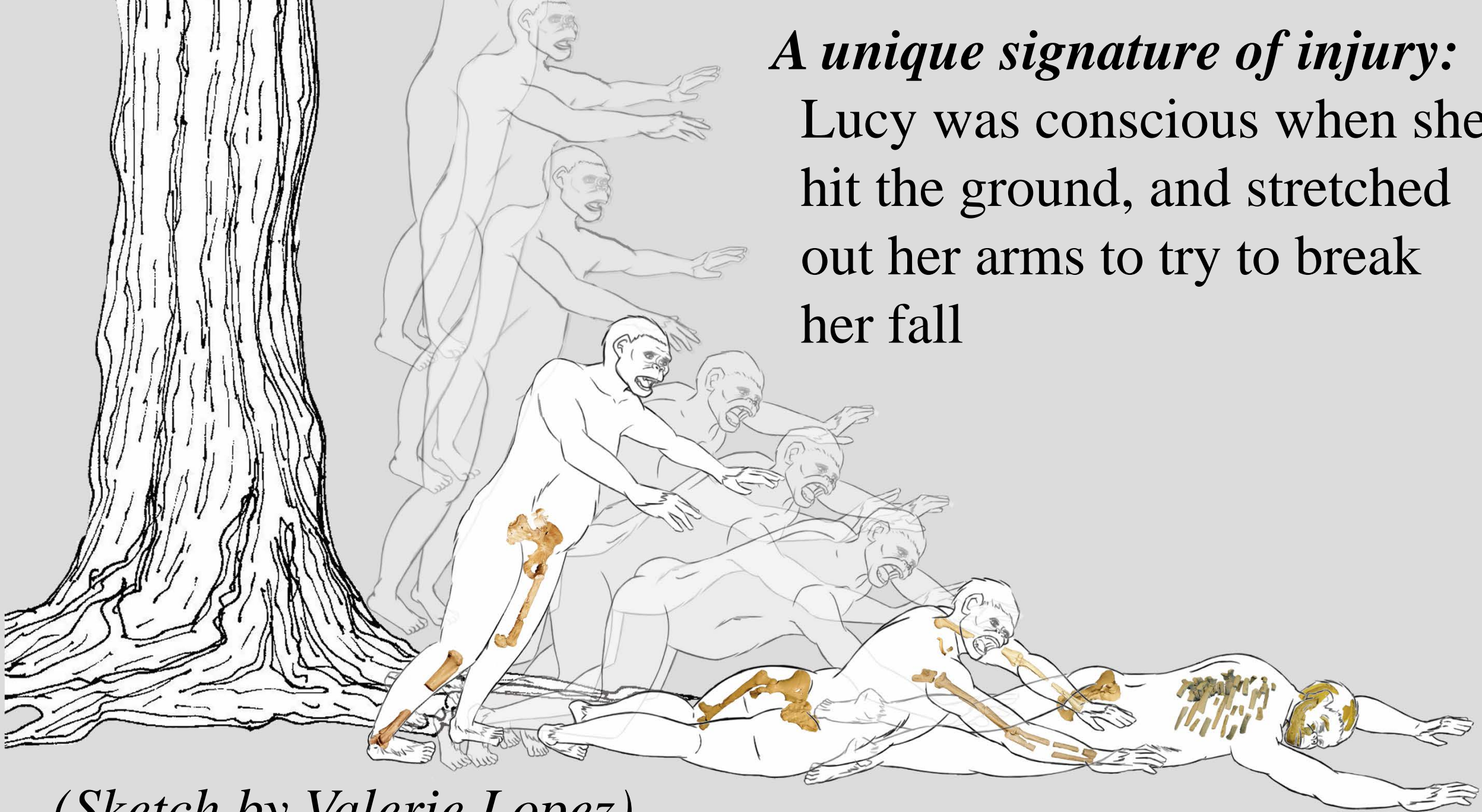
Chimpanzee nest height:
13.7 m = 59 kph (37 mph)
48 m = 110 kph (68 mph)

In addition to the skeletal fractures, it is probable that Lucy suffered extensive damage to her internal organs, and that death followed swiftly.



A unique signature of injury:

Lucy was conscious when she hit the ground, and stretched out her arms to try to break her fall



(Sketch by Valerie Lopez)

How to evaluate our hypothesis? 3D files and printouts

Ethiopia provided release of 3D files so users can download to view or print.

Effort permits a wider and more thorough evaluation of our hypothesis because people can look at the evidence for themselves.

After more than 3 million years, Lucy is leading the charge for sharing the Ethiopian record of fossil hominins!



www.eLucy.org

3D printout of reconstructed right humerus

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Solving a 3.2 Million Year Old Mystery?

- 1) *Did early human ancestors divide their time between the ground and the trees?*
- 2) *Did Lucy die from injuries sustained from hitting the ground after a fall out a tree?*



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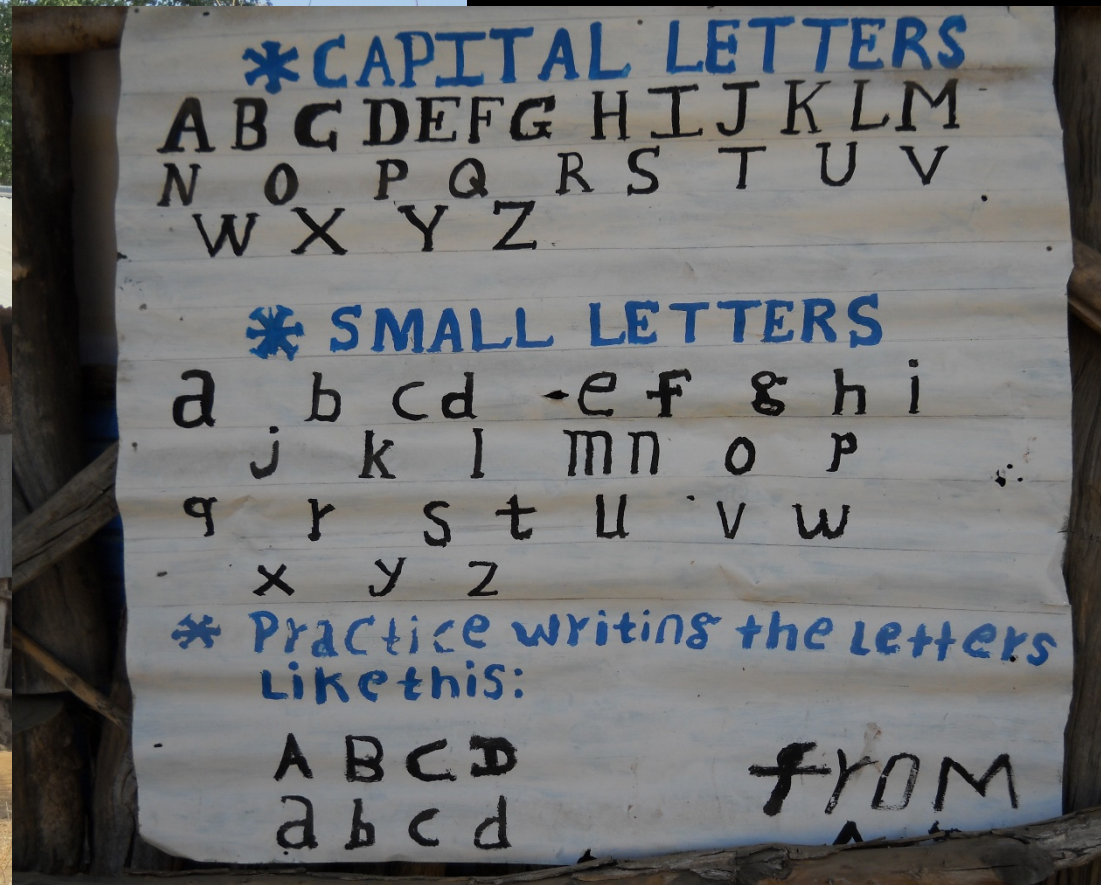


*Receiving,
and giving back...*



*Middle Stone Age Research Experience for
Undergraduates NW Ethiopia 2016*







ABOUT

One Mind at a Time is a group of high school students dedicated to improving the lives of Ethiopian children by giving them access to the best possible education. The group believes that by working in coordination with a select school, we can work on promoting education in Ethiopia and unlocking every student's full potential, one mind at a time.

<http://www.onemindethiopia.org/>

School children in Shinfa village, Ethiopia





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[Thank you!]